The principal function of the older generation of scientists is to discover talent and genius in younger generation and to provide ample opportunities for its free expression and expansion.

— C.V. RAMAN

Thus, the task is, not so much to see what no one has yet seen; but to think what nobody has yet thought, about that which everybody sees

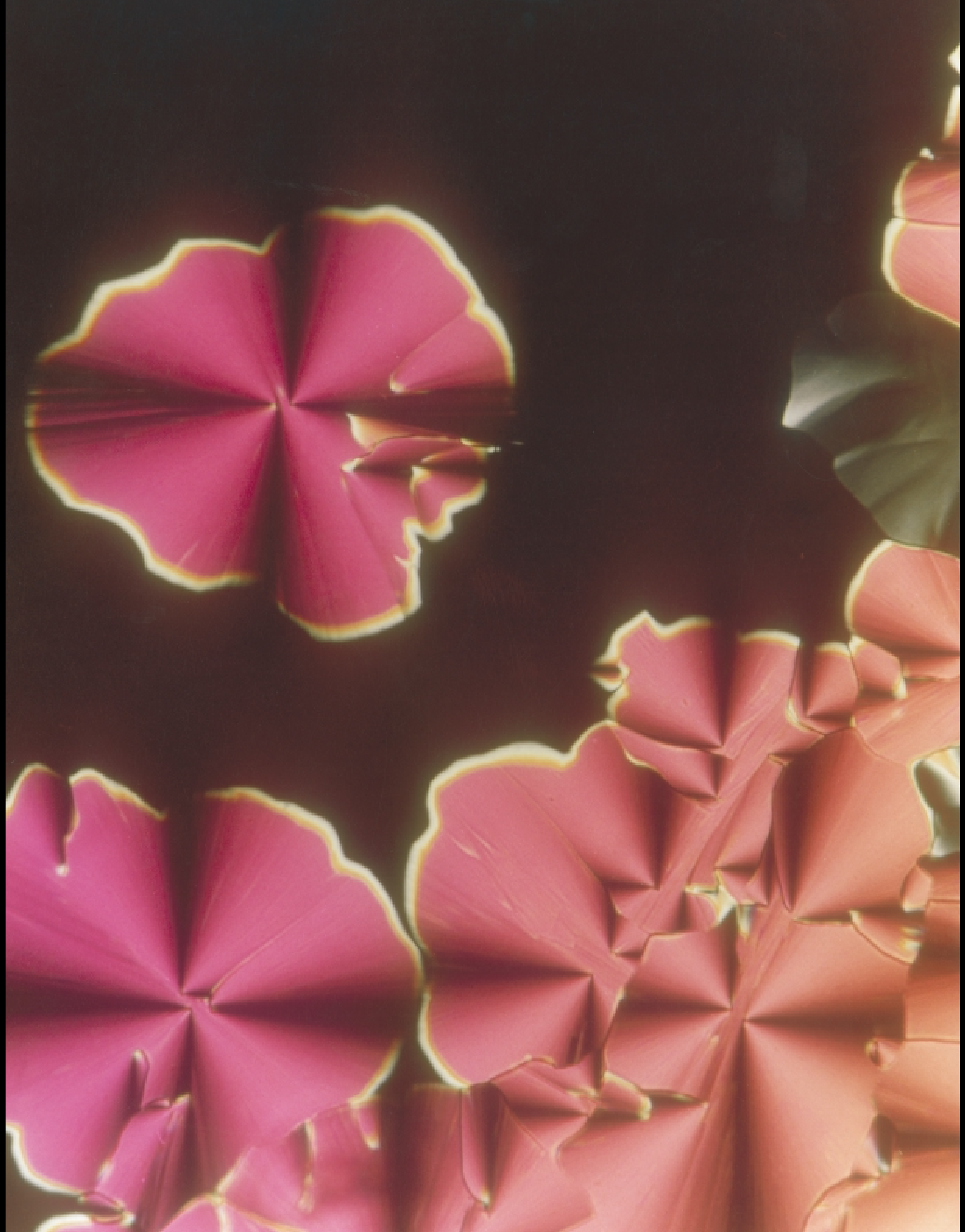
— ERWIN SCHRODINGER

There is no substitute to good scientific work at the bench. It is the work of dedicated scientists which will create an impact on the solution of our problems of economic growth and raise the edifice of science in India.

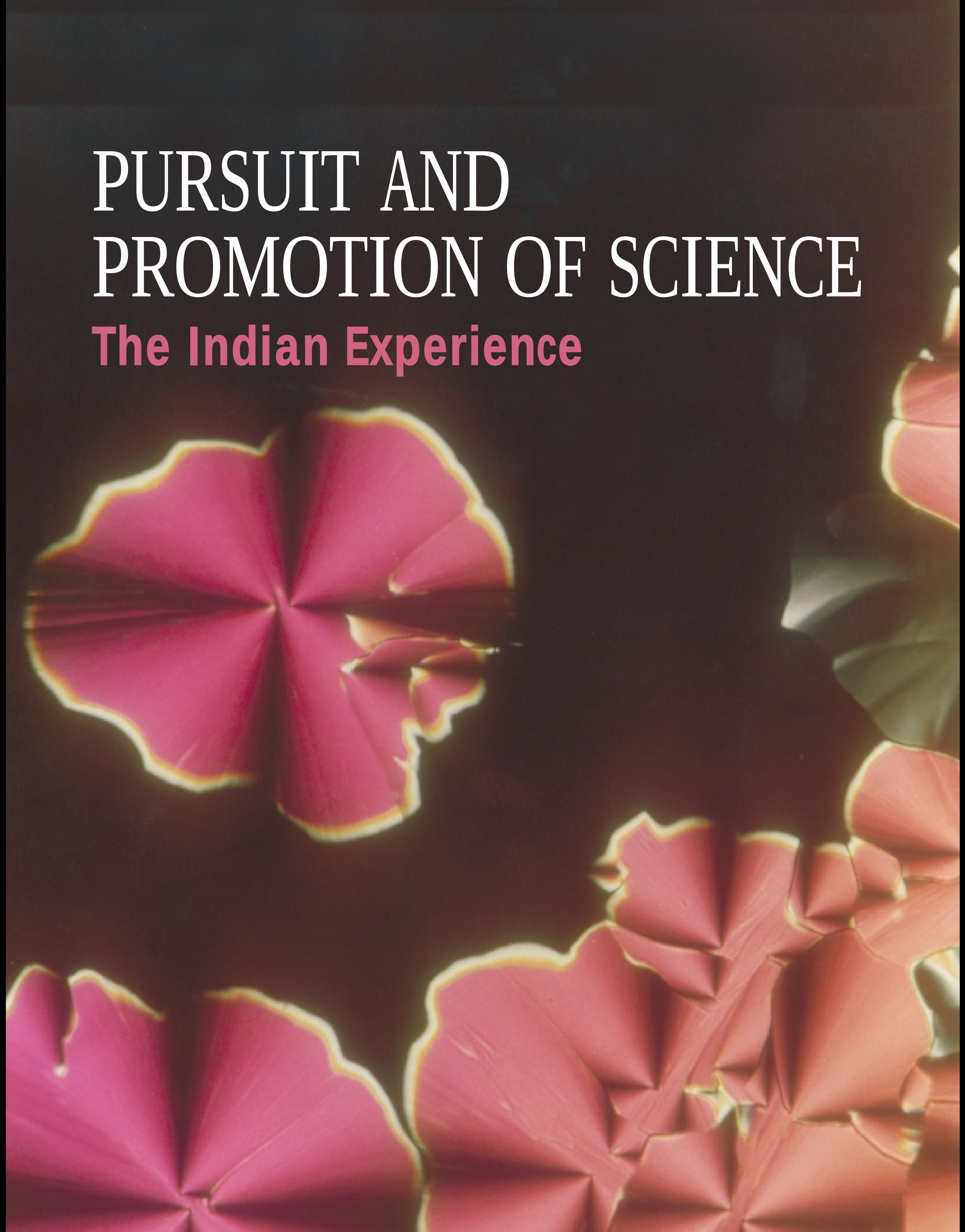
— ATMA RAM

It will surprise most of you to learn that the first Academy was a pleasure garden in Athens which is supposed to have belonged to an ancient Attic hero named Academus.... In this original Academy the old philosophers must have discussed arts and letters, mathematics, and science as well as philosophy strictly so called; so that a true Academy, without qualification, should be on as broad a basis

— L.L.FERMOR



PURSUIT AND PROMOTION OF SCIENCE: The Indian Experience



PURSUIT AND PROMOTION OF SCIENCE

The Indian Experience

A science to be science must afford the fullest scope for satisfying the hunger of body, mind and soul.

Real education consists in drawing the best of yourself. What better book can there be than the book of humanity ?

— MAHATMA GANDHI

Cover: A typical flower texture exhibited by a columnar liquid crystal. This mesophase was discovered (by S. Chandrasekhar and his group) in the compounds made of disc-shaped molecules; Raman Research Institute, Bangalore, 1977

INDIAN NATIONAL SCIENCE ACADEMY

PURSUIT AND PROMOTION OF SCIENCE

The Indian Experience

November, 2001

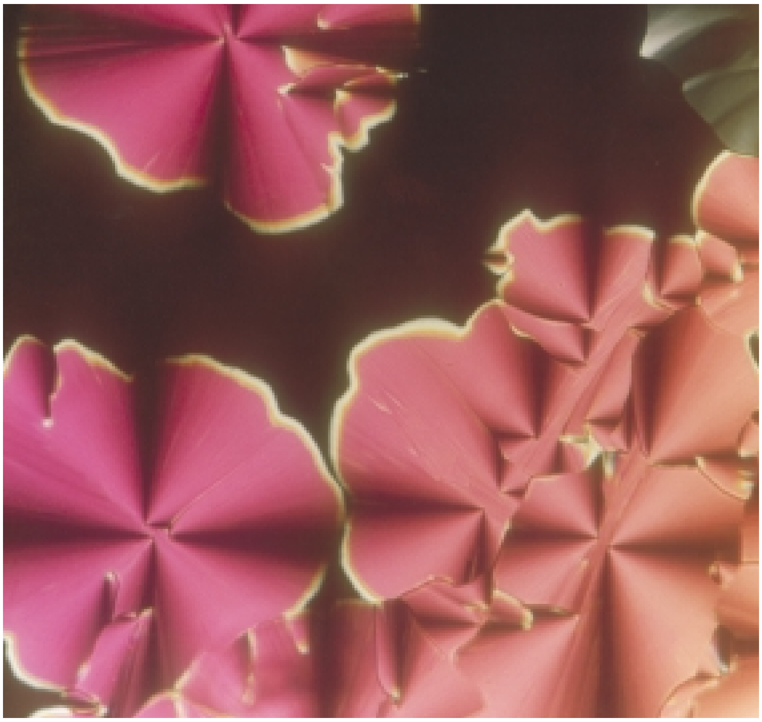
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PURSUIT AND PROMOTION OF SCIENCE

The Indian Experience



INDIAN NATIONAL SCIENCE ACADEMY

CONTENTS

Preface

At the dawn of the new millenium, the Council of the Indian National Science Academy (INSA) considered it desirable to showcase the scientific and technological activities in India, from the time of attaining Independence, and share our experiences with others, particularly with the countries of the South.The present volume *Pursuit and Promotion of Science: The Indian Experience* is the outcome of this endeavour. We were also encouraged to attempt this exercise as the Third World Academy of Sciences had accepted INSA's invitation to hold its General Assembly in New Delhi in October 2001.

Science has been anything but uniform in time and space. Periods of rapid advance have alternated with long periods of stagnation and even of decay. India, along with other older civilizations of Babylonia, Egypt and China, has been a focus of ancient science. Science in India, closely intertwined with culture and philosophy, tempered with wisdom flourished for centuries. However, strong influences of foreign invasions subdued it as the colonial rulers were largely interested in activities which enhanced their own economic prosperity. A well-known historian of science has traced *Our Heritage.*

Resurgence of Science in India came as an offshoot of the nationalist movement, towards the end of 19th century and early decades of the 20th century. Exposure to modern science as we call it today in India is a product of renaissance in Europe. Translation by foreign scholars of ancient Indian writings in Sanskrit which were lying dormant, and the founding of the Asiatic Society played a significant role in this movement. A few exceptionally talented and committed scientists and teachers of that period laid the solid foundation of Indian science by their zeal, dedication and sacrifice. We have built an edifice over it. The Section on *The Torch Bearers of Indian Renaissance* is not merely a tribute to those leaders but is a reminder that science is like a mighty river which keeps flowing through the *guru-shishya parampara.*

Mahatma Gandhi played a monumental role in leading India's freedom movement and inspired exceptional men and women who became architects of modern India. Jawaharlal Nehru, the first Prime Minister of India realized that the economic progress and well-being of the nation depended on science and technology driven development and inculcation of scientific temper among the masses.Thus, science and technology inputs were made an intrinsic part of the planning process and development strategies. Many institutions were created soon after Independence to promote basic research and technological progress. An eminent scientist presents Science and Technology *Since Independence : An Overview.*

During the decades following Independence, through pragmatic policies, a large base for scientific research was created in the universities and through the establishment of

a network of National Laboratories in core disciplines and in newly emerging areas. These early investments paid rich dividends as many notable research contributions emanated from our laboratories and India came to be recognized as a rich centre of trained scientific humanpower. Research contributions from India in diverse branches of science and technology are presented in the Section *In Search of Excellence,* which highlight the most exciting aspects of Indian efforts in advancing the frontiers of knowledge.

The commitment by successive Prime Ministers and Government of India towards promotion of Science and Technology has led to the establishment of several departments and agencies to spearhead programmes in critical sectors. The Section *In Service of the Nation* outlines the efforts made towards attaining indigenous capabilities and global competitiveness in areas ranging from food sufficiency to development of drugs and vaccines for health care and from nuclear energy to satellite launches.

Indian tradition from time immemorial has been to share knowledge and its fruits with the entire humanity. In keeping with this ethos, we lay great emphasis on forging strong links with scientific communities and establishments in other parts of the world. Whereas references have been made to the opportunities for sharing our facilities and possibilities of collaborating research in many of the individual chapters, a separate narrative *International Linkages* reviews the formal bilateral, regional and international programmes that are currently operative. It is hoped that these programmes will encourage the coming together of scientists from the countries of the South in our common endeavour to improve the quality of science and technology and its applications.

In *Looking Ahead,* one of our leading practising scientists reflects upon our achievements and outlines the unfinished agenda for the future.

In the final Chapter, a brief account of *INSA,* the premier scientific body in the country to promote and nurture science and scientists, has been provided.

A volume of this magnitude could not have been possible without the participation and inputs of many persons. For compiling the information, all the Fellows of INSA as well as scientific departments of the Government and its agencies were approached. Individual scientists qualified in special areas were requested to prepare the articles presented here, using the inputs received. All the reports have been suitably edited without sacrificing their flavour. A decision was taken by the Academy to avoid mentioning the names of living persons in the text. I am deeply conscious that in such an endeavour errors, omissions and overlaps are unavoidable. The work of many individuals, institutions and organizations might have remained insufficiently represented. This is entirely unintentional. Names of several cities have recently been changed. For historical reasons the older and internationally familiar names have been retained in the first two sections.

The Academy is beholden to individual scientists for preparing subject-wise articles: *Our Heritage* (B.V. Subbarayappa); *The Torch Bearers of Indian Renaissance* (Rajesh Kochhar and Hasan Jawaid Khan); *Science and Technology Since Independence:An Overview* (M.G.K. Menon); *Science Education* (V.G. Bhide); *Science Olympiads* (P.Arvind Kumar and V.Rao Aiyagari); *Engineering and Technical Education* (D.V. Singh); *Mathematical Sciences* (R. Balasubramanian with inputs from O.P. Bhutani); *Astronomy and Astrophysics* (Ramanath Cowsik with inputs from Govind Swarup and M.G.K.Menon); *Physics* (A.N.Mitra and T.V. Ramakrishnan); *Chemistry* (S.Chandrasekaran); *Earth Sciences* (K.S. Valdiya); *Meteorology and Atmospheric Sciences* (P.K. Das); *India and Global Climate Change* (A.P. Mitra);*Vignettes of Biology* (D. Balasubramanian with inputs from Sudhir K.Sopory); *Plant Sciences* (H.Y. Mohan Ram with inputs from N.P.Singh); *Animal Sciences* (M.S. Jairajpuri and R.Gadagkar with inputs from P.R.K. Reddy, P.K. Sinha and Ranjit Lal); *Medical Sciences* (P.N.Tandon); *Pharmacology and Pharmaceutical Industry* (B.N. Dhawan) ; *Biophysics and Structural Biology* (M.Vijayan); *Biochemistry* (M.R.S. Rao and N.Appaji Rao with inputs from Asis Datta); *Agriculture* (M.S. Swaminathan, Anupam Varma and T.J.Pandian); *Dairy Development in India* (Amrita Patel); *Chemical Engineering and Industry* (M.M. Sharma); *Engineering and Technology for Development* (S. Varadarajan); *International Linkages* (J. Dhar) and *Looking Ahead* (C.N.R. Rao).

This project would not have come to fruition without the advice, support and deep involvement of two of our distinguished Fellows, Professors P.N.Tandon and H.Y.Mohan Ram. We are greatly indebted to them for their whole-hearted effort. Dr.Raja Ramanna, Professors M.G.K.Menon, C.N.R.Rao, S.K.Joshi, V.Krishnan and R.C.Mahajan gave valuable counsel on several matters concerning the preparation of this volume, which is gratefully acknowledged. I also wish to thank all those distinguished fellows of the Academy, heads and senior officers of various science departments and agencies of the Government of India who gave valuable information and help in many ways towards the preparation of this volume.

My special appreciation is extended to Mr.S.K.Sahni and the staff of the Academy, particularly Dr.Alok Moitra, for their dedication and hard work. Dr. Janaki Subramanyam and Dr. Rajesh Tandon deserve acknowledgement for their voluntary help in going through the material for the press.

GOVERDHAN MEHTA
President

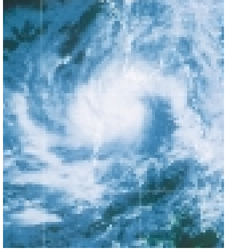
November 5,2001



Photo: H.Y. Mohan Ram

OUR HERITAGE

The Indian civilization, among world's oldest and richest, has a strong tradition of Science and Technology. Our contributions to astronomy, mathematics, medicine and practical arts are not adequately acknowledged in the Western World, either due to ignorance or prejudice. This chapter gives glimpses of the history of our achievements in ancient India.



CHAPTER I

OUR HERITAGE

The Indus Valley Civilization, also called the Harappa Culture that flourished for nearly eight centuries (c. 2750-1900 BC) was, according to some, the youngest but by far the largest of the three most ancient civilizations. It was noted for its efficient town planning with interlinked drainage system, dwelling houses built with standardized burnt bricks, tiled flooring, wheel-turned ceramics, terracotta craft, spinning and weaving, bead-making, and more importantly, copper-bronze casting by the cire-purdue or lost-wax process. Within this civilization flourished many towns and cities including Mohenjo-daro, Harappa, Chanhu-daro, Kalibangan and Lothal, which have revealed an agriculture-based economy with granaries and other storing techniques that made for an enriched community life. While there is wide-ranging archaeological data concerning the technical skills of the people, there is little or no information about their scientific ideas relating to astronomy, mathematics, medicine and the like. This is because their script, found on nearly 3,000 seals, sealings and other inscribed objects, is yet to be deciphered satisfactorily.

The story, however, is different from about 1500 BC with what are called the Vedic people whose literary compositions provide an insight into their culture-specific scientific tradition. The *Ṛgveda*, the earliest of the Vedas, describes in detail the natural law or order called *ṛta* as the governing principle of the universe and its events. Even the Vedic gods were not exempt from this law. In course of time, this principle gave rise to the concepts of truth (*satya*) and *dharma*, the cultural kernel of Indian society. The Vedic seers were also keen observers of the sky. They were well aware of the motion of the Moon, the path of the Sun, occurrence of eclipses and solstices, and had developed luni-solar calendars with methods of intercalation. More importantly, they formulated a stellar frame of reference, in terms of 27 or 28 *nakṣatras* or asterisms (star groups) lying along or near the ecliptic, in order to follow the path of the Moon and Sun. One of the six auxiliaries of the Vedas -- and the earliest Indian astronomical text -- going by the name of *Vedanga Jyotisa* had developed a concept of a cycle of five years for luni-solar and other time



Sealing of a Bull, that is impression of the original seal, Indus Valley, c. 2500-1500 BC.

adjustments, with intercalation at regular intervals. Later, Indian astronomers adopted a huge cyclic period of 43,20,000 years. At the beginning of this mega-cycle, *yuga*, the planets were supposed to be in conjunction and, after going through integral numbers of revolutions in relation to the earth, would accordingly again be back in conjunction.

Indian mathematics too had its origin in the Vedic practices. The *Śulba Sūtras*, a component of another Vedic auxiliary called the *Kalpa Sūtras*, deal with the construction of several types of brick altars for sacrificial performances with the elucidation of certain geometrical problems involving the so-called Pythagorean theorem, squaring a circle, equivalence in area of geometrical figures, irrational numbers and the like. Yet another Vedic auxiliary, *Chandaḥ* (metrics) postulated a triangular array for determining the type of combinations of *n* syllables of long and short sounds for metrical chanting. This was later mathematically developed into a pyramidal expansion of numbers. Such an exercise, known as Pascal's triangle, appeared centuries later in Europe among Renaissance mathematicians. In the Vedic period, number-reckoning on an ascending decimal scale, even up to 1018 (but word-numerals), was developed along with arithmetical and geometrical series. The Jainas and Buddhists too had conceived of very large numbers.

Astronomy and Mathematics

During the three centuries before and after the Christian era, astronomy became based on mathematics. There came up a new class of astronomical texts called the *Siddhāntas* (final solutions), in which the now familiar twelve signs of the zodiac gradually replaced the *nakṣatras* system, along with new astronomical methods for determining mean longitudes, planetary motions, eccentric and epicyclic models, and trigonometrical aspects, all of which point to possible Hellenistic or Greco-Roman influences. The five noted *Siddhāntas* are the *Paitā maha*, the *Vasiṣṭha*, the *Pauliśa*, the *Romaka* and the *Sūrya*. Of these, the last (the *Sūrya Siddhāntā*) is the most accurate, according to Varāhamihira (early sixth century A.D.) who in his *Pañca siddhāntika*, summarized their contents. In any case, this text which underwent some modifications continues to be used as a major basis for traditional calendrical computations even to this day.

Some leading astronomers-cum-mathematicians of this age were Āryabhaṭa I (c.5th AD); Bhāskara I (c.7th), Brahmagupta (c.7th-8th); Lalla (c.8th), Vaṭeśvara (c.10th); Āryabhaṭa II, Śrīdhara and Śrīpati (c.10th-11th) Bhāskarāchārya II (c.12th.), Mādhava (c.14th), Ganesadaivajna (c.15th) and Nīlkaṇtha Somayāji and Paramesvara (c.16th). Āryabhaṭa I gave the value of pi (3.1416 approx.), a value used even today; worked out trigonometrical tables, areas of triangles and other plane figures; arithmetical progression, summation of series and indeterminate equations of the first order. He also expounded the theory that the earth rotates upon its own axis; and the period of one sidereal rotation determined by him is almost equivalent to the modern value. He rejected the traditional Rāhu-Ketu postulate regarding the occurrence of eclipses and provided a scientific explanation instead. Varāhamihira, too, rejected this mythical idea, despite being an astrologer influenced by Hellenic ideas of the twelve zodiacal signs and associated concepts .

Brahmagupta, however, believed in the Rāhu-Ketu postulate and refused to subscribe to Āryabhaṭa's

A thousand years before the time of Copernicus (1473-1543), Āryabhaṭa (b 476 AD) in India made outstanding contributions to astronomy and mathematics. His contributions include: the determination of the diameter of the earth and the moon, the proposal that the earth rotated on its axis to explain the daily motions of the fixed stars; the solution of quadratic equation; defining the trigonometric functions; stressing the importance of Zero; and determining the value of pi up to the fourth decimal place.





Top: An astronomical observatory in Jaipur, built by Maharaja Sawai Jai Singh.
Bottom: Sun dial in the astronomical observatory in Delhi, built by Maharaja Sawai Jai Singh in 1724.

exposition of the earth's rotation, or to his scientific explanation of the eclipses. Nevertheless, he made remarkable contributions towards solving indeterminate equations of the second order -- an equation that appeared in Europe a thousand years later as Pell's equation. His lemmas in this connection were rediscovered by Euler (1764) and Lagrange (1768). Brahmagupta is regarded as the first mathematician to enunciate a formula for the area of a rational cyclic quadrilateral. His works, the *Brahmasphuṭa Siddhānta* and the *Khaṇḍakhādyaka*, were translated into Arabic in the Caliphate at Baghdad under the titles *Sindhind* and *Arkand* respectively. The tradition of astronomy and mathematics continued in the years to come, preceding similar developments in Europe by a couple of centuries in such areas as determination of the precision of equinoxes, parallax, mean and true motions of planets, permutations and combinations, solving quadratic equations, square root of negative numbers and trigonometrical series brought out by Mādhava and others of the Kerala school of mathematics. The twelfth century witnessed the most notable astronomer-cum-mathematician, Bhāskarāchārya II. His cyclic (*cakravāla*) method for solving indeterminate equations of the second order has been hailed by the eminent German mathematician Hermann Henkel as the finest thing achieved in the theory of numbers before Lagrange.

The decimal place-value system, using nine digits and zero, had been developed in India by about the fourth century AD. It may be noted that the Indian *Brāhmī* numerical forms, along with the decimal place-value system, were also well known in the Arabic world. George Sarton, the renowned historian of science, has observed: *Our numbers and the use of zero were invented by the Hindus and transmitted by Arabs; hence the name Arabic numerals which we often give them*. In this transmission, al-Khwārīzmi (c.9th), a Central Asian mathematician who worked in Baghdad, played a seminal role through his work on arithmetic. Al-Kindi and Al-Bīrūnī (c.11th) were the other exponents not only of the Hindu numerical system, but of Indian astronomy as well.

In the eighteenth century Sawai Jai Singh II, a rare Maharaja imbued with scientific zeal, erected huge masonry observatories in Banaras, Mathura, Ujjain, Delhi, and in his capital city of Jaipur.He derived his inspiration from the Maragha school of observatory of Ulugh Beg at Samarqand. The observatories at Jaipur and Delhi, still in good condition, are a testimony to the importance Jai Singh attached to observational astronomy. He was ably assisted by his court-astronomer, Jagannātha Paṇḍita, and possibly by some Jesuit missionaries in his compilation of astronomical tables called Zize-Muhammad-Shāhi, which he dedicated to the Mughal emperor Muhammad Shah.



Surgical instruments described in Sus'ruta Saṃhitā an ancient Indian text on surgery.

Medicine

The science of the body and mind was, and continues to be as important as the science of the heavens. With its origin in the healing art of the Vedic times, Ayurveda emerged as the medical science par excellence by about the fifth century BC. It derived its theoretical sustenance from the philosophical systems namely the *Sāṃkhya* and the *Nyāya-Vais'eṣika* that dealt with certain integrated concepts of man and nature, as also human nature itself. Its foundational matrices for systemized medicinal principles and practices was intimately connected with the five elements called the *pañcamāhabhūtas* -- earth or *pṛithvī*; water or *ap*; light or *tejas*, air or *vāyu* and *ākās'a*, or ubiquitous principle; and these formed an integral part of the two philosophical systems.

The forte of Ayurvedic thought structure is its integral methodological approach towards the physiological processes within the human body as well as the factors influencing them from outside. In this respect, the doctrine of five elements proved to be of immense value. On it was based the postulate of three humours (*tri-dhātu-tri-doṣa* concept) that encompassed not only the metabolic and other physiological processes in the body, but also the pathogenesis of diseases. According to Ayurveda, health is the equilibrium or harmony of the three humours, while their imbalance makes for the diseased state. Ayurveda emphasizes the body-mind concord and the need to examine the patient as a whole, advocating both curative as well as health promotive measures. Its diagnostic procedure is elaborate and its materia medica extensive, comprising largely herbal but also mineral and animal sources.

Behind its effective materia medica lies a rare expertise in intricate preparation of medicinal formulations of a composite character -- a careful selection of the right plants and other ingredients, processing them with equal care, prolonged heat treatment in certain cases, and above all, the right dosage and dietary regimen in consonance with an accurate diagnosis. Ayurveda describes five basic treatments called the *pañcakarma*, which aim at toning the bodily tissues for effective drug action or surgical operation, as also for conditioning the body for medical care. To the Ayurveda, the antidote is necessary but not sufficient, for its aim is to completely eliminate the vitiating roots of the disease.

The two great classics of Ayurveda, the Caraka (c.2nd AD) and *Sus'ruta Saṃhitās* (c.4th AD), present a vivid and cogent account of the medical knowledge and surgical practices respectively that were in vogue

about 1800 years ago and continue to be used in Ayurveda today. Medical historian D.Guthrie records, *It was in surgery, above all, that the ancient Hindus excelled*. The *Suśruta Saṃhitās* which accords pride of place to surgery describes more than three hundred different operations and 121 surgical instruments (20 sharp and 101 accessory) such as tongs, forceps, scalpels, catheters, syringes, speculums , needles, saws, probes, scissors and the like. The outstanding feats of ancient Indian surgery related to laparatomy, lithotomy and plastic operations. The *Suśruta Saṃhitās* is regarded as the earliest document to give a detailed account of rhinoplasty (plastic reconstruction of the nose). It was not before the eighteenth century that plastic surgery made its appearance in Europe. The Roman physician, Celsus (c. 1st AD), gave a vivid account in his medical treatise of lithotomy that was practised in India at that time. Later, another noted physician, Galen of Pergamum who lived in Rome, made no secret of his borrowing material relating to ointment for the eyes and the Indian plaster from Indian sources.

Bronze statue of a dancing girl excavated at Mohenjo-daro, c. 2500-1500 BC.



Transmission

Indian medical knowledge and surgical practices were known not only in the Arabic world but in South-East Asia, Tibet and China as well. The Abbasid Caliphate in Baghdad encouraged the translations of the works of Caraka, Suśrutā, Mādhava and Vāgbhaṭa in the 9th and 10th centuries AD. Al-Razi, the well known physician of that time, incorporated Ayurvedic practices into his comprehensive medical work *al-Hawi*, that later in the thirteenth century was translated into Latin by Moses of Farachi and became a standard medical compendium in Europe in the middle ages.

Said al-Andalusi, an Arab astronomer and historian of science of the 11th century AD, evaluated the scientific achievements of eight cultures up to his time, namely, Hindus, Greeks, Romans, Phoenicians, Egyptians, Chaldeans, Hebrews and Persians. He accorded first place to India and wrote appreciative terms about the scientific inventions of the Hindus as well as their philosophical wisdom. The reason was not far to seek. India had made notable advances in the fields of astronomy, mathematics and medicine. Further, Indian texts on astronomy, mathematics and medicine were well known to Arabic savants and, through their works, to learned persons of Latin in medieval Europe.

This transmission was not one sided. Medicine knows no barriers of region or religion. Around the 13th and 14th centuries, the Greco-Arabic system of medicine entered India with the Muslims and began to flourish, especially under the Mughal rule. Muslim rulers encouraged both the Unani (the name in India for the Greco-Arabic medicinal system) and Ayurveda. *Hakims* and *vaidyas* worked together in hospitals

established by Muslim monarchs. While several Unani treatises written in India listed a considerable number of Ayurvedic practices, the two diagnostic methods of Unani, namely, the pulse and urine examination, were adopted by Ayurvedic practitioners and added to their diagnostic base of *tridoṣa* and other factors.

Techniques

As for technical skills, artisans and craftsmen played an important role in enriching the socio-cultural life of the people over the centuries, thanks to their expertise in metallurgy and metal working, dyes and pigments, casting exquisite copper-bronze icons, pyrotechnics, cosmetics and perfumery. Generally, artisans and craftsmen occupied a low position in the caste-ridden social hierarchy. Even so, some, like the metalsmith achieved recognition through excellence in their techniques. As early as in the fourth century BC, the metalsmith had perfected the complex process of extracting zinc from its ores by the downward distillation method that required exceptional care in the type of furnance, retorts and a reducing atmosphere as well as temperature management, as evidenced by the archaeological finds at Zawar in Rajasthan. It may be noted that it was only in the 18th century that the same process was adopted in Britain, and patented too.

In the Classical Age of India, the metallurgy of iron and copper assumed macro-dimensions. The famous Iron Pillar of the late 4th and early 5th centuries AD, which is seven metres high and weighs over six tonnes, now stands serene near Qutab Minar, Delhi, having amazingly withstood the ravages of time and clime, remaining rust-free for over 1,500 years. Essentially made of wrought iron (99.7 per cent iron) and forge-welded out of iron blocks of appropriate sizes, the Pillar has 0.144 per cent of phosphorus that aids anti-corrosion and contains no manganese and only negligible sulphur, the composites that would cause corrosion. This technique was not short-lived either. In the eleventh century, a much larger iron pillar was forge-welded and now lies free of rust in two or three pieces at



© Pallava Bagla

Iron Pillar at Delhi which has remained rust-free for over 1,500 years.

Dhar in Central India. In the 13th century, several iron beams were fabricated for use in constructing the temples at Puri and Konark in Orissa. The Iron Pillar of Delhi, however, remains unparallelled. Even in 1881, British economic geologist V.Ball recorded: *It is not many years since the production of such a pillar would have been an impossibility in the largest foundries of the world, and even now there are comparatively few places where a similar mass of metal could be turned out.* In the field of copper metallurgy too, the huge fifth century copper statue of the Buddha, over two

metres in height and one tonne in weight, (now in the museum in Birmingham) is a remarkable product of macro-technology.

An equally remarkable micro-technology, namely, the production of high quality steel now known as Wootz steel (an iron-carbon alloy with 1.3 to 1.6 per cent carbon was also in use). This production technique was particularly prevalent in South India and emerged as an accomplished metallurgical technique by about the 6th century, after which Indian steel was sought after for the production of what was termed the Damascus sword in West Asia, around the 10th century AD. Metallurgists in the Universities of Stanford and Iowa State (USA) have investigated Wootz steel with a view to reproducing the ancient Indian process. The former have even patented a process for the production of Utah-High-Carbon steel (1.3 to 1.6 per cent carbon) that could be used for certain automobile and aeroplane components.

A veritable index to India's scientific tradition is the appreciably large number of manuscripts, mostly in Sanskrit, that have been preserved in over a hundred repositories both in India and abroad. They encompass the disciplines of astronomy, mathematics, medicine, and also such techniques as metal-working including iconography, dyeing, cosmetics and perfumery. While the major texts have been studied, a considerable number of manuscripts remain unexplored. In any case, they have fostered scientific pursuits for over a millennium.

India Meets Western Science

With its long scientific tradition, India did not view western scientific ideas and technical practices as something alien to its own ethos. Instead, it gradually began to participate in the new movement when western science was introduced into India by the British in the latter half of the eighteenth and in the nineteenth centuries. Despite the oppressive colonial regime, in the early decades of the twentieth century Indian scientists came up with outstanding contributions even in the frontier areas of science of the time.

In the mid-seventeenth century the Governor of Dutch Possessions on the Malabar coast, Henrich Van Rheede Drakenstein (1637-1692), investigated a number of plants and seeds with the help of some European medical men as well as medical practitioners of Malabar. His work *Hortus Malabaricus* was published in 12 volumes (Amsterdam: 1683-1703; with 794 plates). This botanical work was of immense value to the then famous Swedish botanist Karl Linnaeus in the nomenclature of Indian plants in his *Species Plantarum*.

The turning point in the history of botanical investigations in India was the inception of the Royal Botanic Garden in 1787 at Sibpur near Calcutta. By then the British had established their political supremacy, having won the Battle of Plassey (1757). There were several distinguished botanists like William Roxburgh, Buchanan Hamilton, Nathaniel Wallich, William Carey, George Govan, J.F.Royle, C.B. Clarke and George King, whose botanical investigations in India added a veneer of excellence to global botany and their voluminous publications enriched botanical knowledge of the times.

To further their political ambitions that also required a thorough geographical knowledge of the new land, the British colonial masters undertook a topographical survey and soon developed what was known as the Great Trigonometrical Survey of India. In the first half of the nineteenth century, William Lambton in the south and George Everest along with Andrew Waugh in the north, emerged as the most notable surveyors. Waugh was able to determine the heights of major Himalayan peaks, which numbered about 80. He named the highest of these peaks (29,002 ft. above mean sea level) Mount Everest after the Surveyor-General of India. Among Indian technicians who worked with George Everest and Andrew Waugh, special mention needs to be made of Radhanath Sikdar and Mohsin Husain. The former was noted for his mathematical acumen and computing ,while the latter was a versatile maker of mathematical instruments who reconstructed a theodolite (now preserved in the Victoria Museum at Calcutta) that was used by Waugh and his associates.

The mineral wealth of India was indeed a source of special attraction for the British. In course of time, the Deccan, Central and North India, as well as the Himalayas, were explored for their mineral wealth and geological formations alike. Palaentological studies too were undertaken in the Siwalik Hills region by Hugh Falconer and the engineer Proby Cautley . Falconer brought to light the remarkable fossile fauna of the sub-Himalayan range, which earned him a distinguished position among palaentologists. The Geological Survey of India was established in 1851. Several geologists like Thomas Oldham, W.T. Blanford, H.B. Medlicott, William King and Thomas Holland made oustanding contributions to Himalayan geology, and to the discovery of large deposits of iron and other ores. Earthquakes were also studied. Towards the end of the nineteenth century there were two Indian officers in the Geological Survey of India, P.N. Bose and P.N. Dutta. The former mapped the Vindhyas and the igneous rocks of Raipur and Balaghat areas, while Dutta discovered the vast deposits of manganese ore in the Bhandara and the Chhindwara riverine area. Bose was also instrumental in discovering the extensive and rich deposits of iron ore in Mayurbhanj. Later, on his advice, the pioneering industrialist Jamshed Tata and his son Dorab Tata took active steps for the establishment of an iron and steel factory in the first Indian industrial enterprise -- in Jamshedpur - where TISCO is still located today.

Meteorological and astronomical studies also made some progress during this period. A notable development was the study of the law of storms, and the term 'cyclone' was coined by H. Piddington for the serpent-like coiling of a severe storm. The India Meteorological Department was established in 1875. H.T. Blanford, John Eliot and Gilbert Walker were among the noted meteorologists. A bright Indian assistant, Ruchi Ram Sahni, was associated with the preparation of daily weather reports. As for astronomical studies, as early as in 1792, an observatory was established in Madras on the initiative of William Petrie, a member of the Madras Government. John Goldingham, T.G. Taylor, H.Warren and others compiled a star catalogue of about 11,000 stars. N.R. Pogson made discoveries of asteroids and variable stars, with which C. Raghoonathachary was also associated. In 1900, the Solar Physics Observatory came up at Kodaikanal in Tamil Nadu. From the older observatory in Poona, called the Maharaja Takhatsingh Observatory, K.D. Naegamvala made significant observations of the solar phenomena, and especially of the eclipse that occurred in 1898. Evershed, who succeeded to the Directorship of the Kodaikanal Observatory in 1911, studied solar prominences and their penumbra, and discovered the radial motion in sunspots.

English Education

In 1813, when the Charter of the East India Company was renewed, a provision was made for not less than one hundred-thousand rupees each year to be spent by the Company on educating the natives. But the real turning point came when some liberal Indians like Raja Ram Mohun Roy advocated the introduction of scientific subjects. In 1935, the colonial government adopted English as the medium of instruction, and began to encourage the promotion of western learning, including science. The first three universities were established in 1857 at Calcutta (January), Bombay (July) and Madras (September). The new universities functioned only as affiliating and examining bodies in the faculties of law, science, medicine and surgery and civil engineering, besides the arts while their courses in scientific and technical education was determined by the exigencies and self-interest of the colonial government. Towards the turn of the nineteenth century, there were five universities, including the two established in Lahore (1882) and Allahabad (1887); about 170 colleges, mostly concentrated in cities, among which were some 40 professional colleges -- about 30 for law and four each for medicine and engineering; besides some medical, engineering, agricultural and industrial schools. However, the foundation laid for scientific and tech-

nical education left much to be desired.

The colonial government did promote field investigations to some extent and set up a few scientific institutions besides the scientific survey organizations. These were mainly intended to further British exploitative commercial interests and political hegemony. There emerged, nevertheless, a few isolated endeavours towards creative science, like the law of storms and cyclones by H. Piddington; the theory of isostasy by A. Pratt; the concept of Gondwanaland relating to continental dynamics; the discovery of the carrier of malarial parasite by Ronald Ross, and the Evershed Effect in solar physics. Unfortunately these endeavours did not generate critical discussion nor did they lay a solid foundation for the promotion of research, fundamental or applied. The colonial government's attempt at introducing western science in India was a formal one. But its real introduction was undertaken by Indian pioneering scientists and other leaders who provided critical inputs and inspiring leadership as well as an innovative climate, starting from the last quarter of the nineteenth century.

Scientists as Pioneers

In 1876 Mahendra Lal Sirkar (1833-1904), an enlightened medical practitioner, established the Indian Association for the Cultivation of Science at Calcutta, recognizing that the time had come when Indians themselves should cultivate science and imbibe its rationality. It was in this institution that over fifty years later, C. V. Raman (1888-1970) conducted his epoch-making research on light-scattering, now known as the Raman Effect (1928) that earned him the Nobel Prize in Physics (1930). In Bombay, a rare visionary and industrialist, J. N. Tata (1839-1904) in pursuit of his avowed objective of national regeneration, endeavoured to set up a university for imparting higher education to Indian students. The path was by no means easy. It eventually took the form of the Indian Institute of Science at Bangalore (1909-1911), which began to play a seminal role in the subsequent growth of science and technology in India.

Asutosh Mookerjee, a brilliant mathematician, became the architect of the Calcutta University in the early decades of the twentieth century, opening up various avenues of postgraduate teaching and research. It was he who persuaded scholars and scientists from diverse regions of the country to join the faculty or accept the chairs offered. Earlier, towards the closing years of the nineteenth century, Jagadis Chandra Bose (1858-1937), the first Indian Professor at the Presidency College in Calcutta, became a trendsetter in stretching the capabilities of Indian scientists. He devised his own instruments with ingenuity and succeded in the generation, transmission and reception of electromagnetic waves of wavelengths between 5 mm and 25 mm -- a pioneering contribution of that time. He demonstrated his experiment at the Royal Institution in London, but was disinclined to patent his discovery. J.C. Bose also demonstrated that not only animal tissues but also plant tissues, under different kinds of stimuli, would produce similar responses. He also set up an institute, the Bose Institute at Calcutta.

P.C. Ray (1861-1944), an outstanding chemist, built up a school of chemical research and initiated effective steps towards the establishment of certain chemicals, especially in the pharmaceutical industry. C.V. Raman, too, energized a flourishing school of research in physics, both at Calcutta and at Bangalore where he held the posts of Director (1933-37) of the Indian Institute of Science and Head of the Department of Physics till 1948. He established a research institution, the Raman Research Institute at Bangalore, with his Nobel Prize money and other resources.

Contemporaneous with Raman were other scientific leaders who laid a solid foundation for scientific research. The most notable among them were Srinivasa Ramanujan (1887-1920), K.R. Ramanathan (1893-1985), M.N. Saha (1893-1955), P.C.Mahalanobis (1893-1972), S.N.Bose (1894-1974), S.S.Bhatnagar (1894-1955) and K.S. Krishnan (1898-

1961). Ramanujan became a legendary figure in mathematics and his mathematical acumen is still a marvel. M.N. Saha earned international acclaim for his theory of thermal ionization and radiation, which explained the ordered sequence of the spectra of stars. His classmate, S.N. Bose, a brilliant theoretical physicist, developed a method of statistics of an assembly of photons in a six-dimensional phase, which was later extended by Einstein, now known as the Bose-Einstein Statistics. The discovery of particles that followed this are now called 'bosons' in honour of S. N. Bose. K. R. Ramanathan worked on the scattering of light and also made outstanding contributions to meteorology. P.C. Mahalanobis was renowned for his originality in theoretical statistics and later played a prime role in socio-economic planning. S.S. Bhatanagar made a distinct mark in magneto-chemistry, its principles and applications. K.S. Krishnan, who was intimately associated with the discovery of the Raman Effect, was noted for his significant work on the properties of crystals.

The University system had expanded, although not to the desired extent, from five at the beginning of the twentieth century to seventeen on the eve of Independence. Several research institutions, including those for agriculture, had also come up. During this period, the freedom movement that had gathered momentum was a source of inspiration to scientists to pursue original research, despite the regressive colonial ambiance. The freedom movement was led by Mahatma Gandhi and his chosen political heir, the charismatic Jawaharlal Nehru who, though not a laboratory scientist, had a broader vision of science, its rational methods, and applications for the benefit of people . In his book, *Discovery of India*, which he wrote during imprisonment, he exhorted: *Who can ignore science today? The future belongs to science and to those who make friendship with science*. India's friendship with science is in no small measure due to Nehru, since he was convinced that science and science alone could lead poverty-stricken India into prosperity. He emphasized the importance of the scientific method or temper as he called it, insisting that it should permeate all sections of society. He was instrumental in setting up a sub-committee on Technical Education and Development Research (1939) under his chairmanship of the National Planning Committee (1938) and this was in the thick of the freedom movement.



The old building of the Asiatic Society which also housed INSA offices from 1935-1945.

In the middle of 1939, Homi Bhabha, who had done outstanding research on cosmic rays in Copenhagen and Cambridge, was in India for a short recess at the Indian Institute of Science at Bangalore. World War II which broke out soon after prevented his return to England. Bhabha set up a Cosmic Research Unit at the Indian Institute of Science and the Tata Institute of Fundamental Research at Bombay in 1945. Three years before this, the Council of Scientific and Industrial Research had been set up with Bhatnagar as its Director. When Nehru took over as India's first

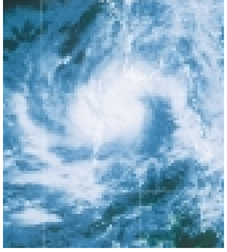
Prime Minister in 1947, Bhabha and Bhatnagar played pivotal roles in strengthening the country's scientific and technological base. Bhabha thought of 'Big Science' (then nuclear physics and energy) and Bhatnagar conceived of 'Science in a big way' through a chain of national laboratories. Both received unstinted support from Nehru. In perspective, it is evident that the Indian scientific pioneers, Nehru, and other leaders laid a viable scientific foundation well before Independence for the multi-level growth of science and technology in Independent India. It is , nevertheless, significant that traditional astronomy co-exists with modern astronomy; traditional medicine is in some manner complementary to modern medicine. Likewise, traditional technologies have carved a place for themselves among the plethora of new and sophisticated technologies.

In several ways, India's past is also its present.



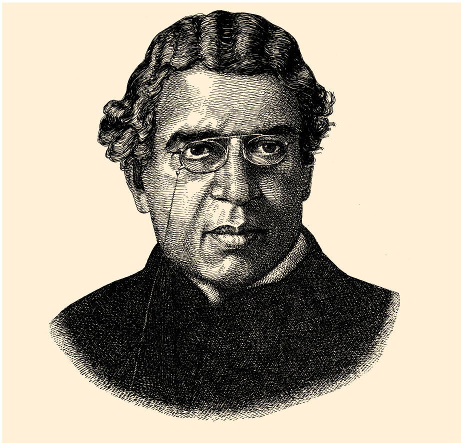
THE TORCH BEARERS OF INDIAN RENAISSANCE

The last decades of the nineteenth and early decades of the twentieth century witnessed a national awakening in all spheres of creativity. The 'Indian renaissance' also produced outstanding scientists. Fired by nationalism, disregarding comforts, and undeterred by severe handicaps, these men did world-class science by indomitable will. We stand on their shoulders today. The thumbnail sketches of the torch bearers present their travails and triumphs. We pay our homage to these masters who gave us strength and confidence.



CHAPTER II

Torch Bearers of Indian Renaissance



JAGADIS CHANDRA BOSE*

1858-1937

On November 30, 1858, at Mymensingh (now in Bangladesh), a son was born to Bhagawan Chandra Bose and Bama Sundari Devi. The child was named Jagadis or Lord of the World. True to his name J. C. Bose grew up to be known as a scientist of world repute.

Young Jagadis spent the early years of his life in Faridpur where his father was posted as the Deputy Magistrate. It was the time spent in Faridpur that Bose would value greatly in his later years. He was brought up in a house steeped in Indian tradition and culture and was sent to the village *pathshala* to study with the common folk. As he spent time with sons of farmers and fisherfolk, he learnt the lesson of what constitutes true manhood. From them he also drew his love for nature.

Young Jagadis was a curious lad, always asking questions. When he saw a firefly he had to know what that 'spark' was. The fast-moving river with fallen leaves floating by, the sprouting of seeds and growth of plants, the attraction of the moth towards light, the shooting stars, all were curiosities he was impatient to understand. He wouldn't rest till he found a satisfactory answer. His father was always there to respond to his child's curiosity and encouraged him, saying *as you grow bigger and bigger, my boy, try to find out the truth yourself*. However, it was not all work and no play for Jagadis, who loved sports too. Cricket was his favourite game.

At the age of nine Jagadis was sent to Calcutta. There he enrolled first at Hare School and later, in St. Xavier's where his lack of proficiency in English made him the butt of jokes. His European classmates refused to accept this rustic boy as one of them. One day unable to tolerate the bullying from a champion boxer, he took up the challenge. In the fight that followed Jagadis won and gained the respect of his classmates. Thereafter, no one dared to tease him.

At St. Xavier's, Jagadis studied physics under Father Lafont who was then a name to conjure with for his brilliant and unique methods of teaching physics with actual experiments. From him too, he picked up the flair for lecture demonstrations. However, botany continued to enthrall him. He would pull out germinating plants to check their roots and grew flowering plants and closely observed their growth. Jagadis passed the School Final examination with a First Class.

* His name has been spelled in different ways in the literature

After graduating at the age of 19, Jagadis had a strong desire to go to England and sit for the Indian Civil Service Examination, but his father would not allow him to do so. He told his son in no uncertain terms that he was to rule nobody but himself, was to become a scholar, not an administrator. Hence, in 1880, Jagadis did go to England but to study medicine at the University of London. There, he suffered repeated attacks of malaria, which he had contracted prior to his departure for London and had to move to Cambridge on a scholarship to study Natural Science at Christ's College. At Cambridge, he came under the influence of such illustrious teachers as Lord Rayleigh, Sir James Dewar, Sir Michael Foster and Francis Darwin.

Jagadis passed the Tripos examination with distinction. In 1884, he was awarded a B.A. degree from Cambridge and next year a B.Sc. degree from London University. Once he got his degrees, he did not linger abroad but returned to serve his motherland. In 1885, he was offered the post of officiating Professor of Physics at Presidency College, Calcutta. He was paid a salary half of what the British teachers were paid, so Bose refused to draw his salary at all as a protest. He worked in an honorary capacity for three years, not missing his classes even on a single day.

In England, Bose had appreciated the 'hands on' approach to science. Back in India, he carried on in the same spirit. Instead of boring verbal lectures, he enlivened his classes by holding extensive demonstrations. This was quite an innovation in those days and Bose became extraordinarily popular with his students. He encouraged them to observe, to question, to experiment and to innovate, without depending solely on books or teachers. After three years, the college Principal Twany and Director Croft, impressed by his brilliance, jointly recommended full salary for him from the date of his joining the college. Bose realized that the best way to face the English was to face them with courage and will power. This he did all his life.

In 1887, Bose married Abala Das, daughter of a leading advocate of the Calcutta High Court and a political leader. Bose's wife was his constant companion and helpmate, accompanying him on his trips to religious and historical places in India and on many excursions to the Himalayan peaks and glaciers. Later in life, she joined her husband on all his lecture tours abroad. Bose dedicated his book *Plant Autographs and their Revelation* (1927) to Abala Devi with the note, *To my wife, who has stood by me in all my struggles*.

When Bose first joined the Presidency College, there was no laboratory worth the name. However, Bose went ahead with his research, in a small enclosure adjoining a bathroom that he converted into a laboratory where he carried out experiments on refraction, diffraction, and polarization. Bose would stay on in the laboratory after the classes were over and carry on experiments. He met the expenses for the experiments himself. He even fabricated the equipment he needed by sheer ingenuity.

The experiments performed in the makeshift laboratory finally resulted in the invention of a device for producing electromagnetic waves. In November 1894, Bose gave the first public demonstration of wireless transmission using electromagnetic waves to ring a bell and to explode a small charge of gunpowder from a distance. He used microwaves with wavelengths in the millimeter range, not radio waves. Considering the very primitive workshop facilities available in Calcutta at this time, the compact nature of his apparatus excited many and drew a great deal of appreciation in England. It was described in many textbooks of this period by J. J. Thomson and Poincare. The Daily Chronicle (England) reported, *the inventor has transmitted signals to a distance of nearly a mile and herein lies the first and obvious and exceedingly valuable application of this new theoretical marvel*.

In recent years, some Indian scientists have spearheaded a movement to give Bose his due

recognition as the Father of Wireless Telegraphy. For, it was more than a year after the successful demonstration of his experiment that Guglielmo Marconi patented this invention. It is believed that it was Bose's failure to seek a patent that denied him his due. However, by all accounts, Bose was never interested in money. The British navy was interested in his coherer (device that detects radio waves) to establish radio links between ships and torpedo boats. So it is not as if Bose was unaware of the monetary worth of his findings. He wrote to Rabindranath Tagore in 1901, *....I wish you could see that terrible attachment for gain in this country....that lust for money...Once caught in that trap there would have been no way out for me*.

Later, Bose developed the use of Galena crystals for making receivers, both for short wavelength radio waves and for white and ultraviolet light. His pioneering work in the field was recognized by his peers. Sir Neville Mott, who won the Nobel Prize in 1977 for his contributions to solid state electronics, went on record stating that, *J.C. Bose was at least sixty years ahead of his time.... In fact, he had anticipated the existence of P-type and N-type semi-conductors*.

Bose's first paper published in the *Proceedings of the Asiatic Society of Bengal* in May 1895, deals with the polarization of electric waves by double refraction. In October 1895, his first communication to the Royal Society of London was published in its Proceedings. The next year, he was conferred D. Sc. by London University for his thesis on *Measurements of Electric Rays*, Bose went to England in 1897, where he not only repeated his demonstrations successfully but also speculated on the existence of electromagnetic radiation from the sun. Two years later, Bose unveiled his invention of the mercury coherer with the telephone detector. The same year he unfortunately lost his diary containing the account of his invention and a prototype of the detector.

Bose devoted a great deal of attention to the peculiar behaviour of his coherer, which consisted of a number of contacts between metal filings whose resistance altered under the impact of electric radiation. Detailed investigation led him to the view that this coherer effect was characteristic of a large class of compounds, like selenium, iron oxides, etc. In fact, Bose can be considered a pioneer in the field of investigation of the properties of photo-conductivity and contact rectification shown by this class of semi-conductors. His subsequent study of the fatigue phenomena exhibited by these substances led Bose to postulate his theory of the similarity of response in the living and the non-living. He found that the sensitivity of the coherer decreased when it was used for a long period -it became tired. When he gave the device some rest, it regained its sensitivity which, in his view, indicated that metals had feelings and memory !

During 1897-1900, Bose turned his interest to comparative physiology, plant physiology in particular. The main focus of his investigations was to establish that all the characteristics of response exhibited by animal tissues are equally exhibited by plant tissues. In 1901, Bose submitted to the Royal Society a preliminary note on the *Electric Response of Inorganic Substances*, in which he showed how he had obtained strong electric response from plants to mechanical stimuli. However, the paper was not published due to the opposition of Sir John Burdon Sanderson, the leading electro-physiologist of the time. In 1904, Bose submitted a series of papers, once again to the Royal Society, showing the similarities of both the electric and mechanical responses of plants and animals. But these papers too met the same fate.

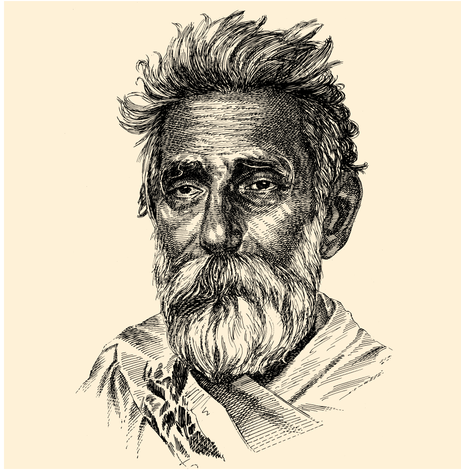
His interest in physiology gave an impetus to his inventive genius. For obtaining the records of mechanical response of plant tissues, he first introduced the optical lever in plant physiology to magnify and photographically record the minute movements of plants. He perfected the resonant recorder that enabled him to determine with remarkable accuracy, within a thousandth part of a second, the latent period of response of the touch-me-not plant, *Mimosa pudica*. He also devised the oscillating recorder for making minute lateral leaflets

of the telegraphic plant (*Desmodium gyrans*) automatically record their pulsating movements. He even took up the problem of recording micrographic growth movements of plants by devising the crescograph. With this instrument, he obtained a magnification of 10,000 times, and was able to record automatically the elongation growth of plant tissues and their modifications through various external stimuli. Later, he perfected his magnetic crescograph obtaining a magnification from one to ten million times. A demonstration of the crescograph at the University College of London on April 23, 1920 led several leading scientists to state in *The Times*: *We are satisfied that the growth of plant tissues is correctly recorded by this instrument, and at a magnification from one million to ten million times*.

The 1900s marked a spell of renewed activity. He attended international conferences and wrote books and research papers. In 1903, he was conferred Companionship of the British Empire (C.B.E.) by the British government. In 1912, he received the Companionship of the Star of India (C.S.I.). The University of Calcutta conferred on him an honorary D.Sc. The Royal Society which had been publishing his papers on physical research since 1894, but had raised serious objections to his physiological research, honoured him in 1920 by electing him a Fellow. In 1933 and 1935, Banaras Hindu University and Dhaka University, respectively, awarded him honorary D.Sc. He formally retired from Presidency College in 1915, but was appointed Professor Emeritus for the next five years.

Bose was not interested in making money. He could have made millions by simply patenting his inventions but more important for him was to spread knowledge. Towards this end, he had nurtured a life-long dream of establishing an institute of excellence. Conceived at least twenty years earlier, the Bose Institute was inaugurated in Calcutta on November 30, 1917. *This is not a laboratory*, he had said, about his Institute, *but a temple*.

Bose died on November 23, 1937, just a week short of his eightieth birthday.



PRAFULLA CHANDRA RAY

1861-1944

An ardent advocate of large-scale industrialization, Prafulla Chandra Ray was the driving force behind the setting up of several industries at a time when the process had hardly begun in India. He was himself a pioneer in the field of pharmaceutical industry in India and started out by making chemicals at home. Looking at foreign companies making excessive profits at the cost of Indian patients, he set up his own company to manufacture inexpensive drugs.

Prafulla Chandra Ray was born on August 2, 1861 in Raruli-Katipara, a village in the District of Khulna (now in Bangladesh). His father, Harish Chandra Ray, was a landlord from a wealthy and cultured family who felt the need to provide education to all. So he set up a middle school in his village and another solely for girls. From his father, Prafulla imbibed an interest in education, rational thinking and sympathy for the poor.

Young Prafulla enrolled in the school his father had set up but often played truant. In 1870, the family moved to Calcutta so that the children could have higher education and Prafulla was admitted to the prestigious Hare School. But a severe attack of dysentery forced him to drop out of school for two long years. This break from the dreary school routine were a blessing in disguise. Prafulla found time to satisfy the passion to study English and Bengali literature. When barely ten years old, he had already learnt Latin and Greek and studied the

histories of England, Rome and Spain.

Prafulla resumed formal education in 1874 at the Albert School which had been set up by Keshab Chandra Sen, a pillar of the Brahmo Samaj movement. Prafulla's knowledge of English literature greatly impressed the teachers of the Albert School, but just when everyone expected his success, Prafulla suddenly left for his village, without even sitting for the examinations. There, he stayed for two years sharing the joys and sorrows of the simple villagers and helping them in whatever way he could.

In 1876, Prafulla returned to Calcutta to resume his studies at the Albert School. This time he worked hard and stood first in the examinations. He passed the Entrance Examination in 1879 and joined the Metropolitan Institute (now called Vidyasagar College). Meanwhile, the sudden demise of his grandfather, Ananda Lal Ray, brought a period of great uncertainty in the family's life, for Ananda Lal breathed his last before he could tell his son where he had buried the store of gold and gem stones-the family fortune, so to say. Prafulla's father tried in vain to find the treasure till the situation got so bad that the ancestral property had to be sold to pay the creditors. To save money, the family shifted back to Raruli while the sons lived on in rented rooms in Calcutta.

At the Metropolitan Institute, Prafulla was immensely influenced by great teachers like Surendranath Banerjee and Prasanna Kumar Lahiri. While pursuing his studies in the Metropolitan Institute, Prafulla would also attend lectures by Alexander Pedlar on Chemistry in the Presidency College. Pedlar's inspiring lectures led Prafulla to take up Chemistry for his B.A., although his first love was literature.

During those days, the London University conducted competitive examinations for the Gilchrist Prize Scholarship for higher studies in Britain. Prafulla decided to take this and he had an added advantage of knowing several languages including Sanskrit and French. And when the results were announced, Prafulla had made it along with a *Parsee* boy from Bombay, named Bahadurji. Although Prafulla's father readily agreed to his son going abroad, his mother was distressed. Prafulla consoled her saying, *When I return from England, I will get a high position. My first duty will be to repay the debts and to repair our ancestral home*.

In 1882, Prafulla left for Britain. The 33-day long voyage left him very weak. Once he reached London, fellow Indian students there helped him out with woollen clothes for the bitter cold of Edinburgh, where he was to join the B.Sc. class in the University.

In 1885, Prafulla wrote an essay on *India before and after the Mutiny*, for the University of Edinburgh prize for the best article. Although the prize went to another student, the judges considered Prafulla's essay of a very high standard. The essay was full of criticism of the British rule in India, it also had a touch of wit. Prafulla had his essay printed and sent copies to his fellow students, appealing to them for help in the task of liberating India. He also sent a copy to the great parliamentarian, John Bright, who was regarded as a friend of India. Bright sent a very sympathetic reply and authorized Prafulla to use the letter in any way he liked. Prafulla lost no time in sending a copy of Bright's letter to the *London Times* and other leading British papers. One fine morning, when the papers came out with the headline *John Bright's letter to an Indian student*, Prafulla became a celebrity.

Prafulla took his B.Sc. degree in 1885 and went on to do research in Chemistry for the D.Sc. degree of the University of Edinburgh. In 1887, at the age of 27 he was awarded the D.Sc. degree. He also received the Hope Prize Scholarship of the University, which enabled him to continue his work for another year. Prafulla returned to India in 1888 with recommendations from his professors. But back home, even with a D.Sc. degree he could not land a job and spent almost a year working with his famous friend Jagadis Chandra Bose in his laboratory. A year later Prafulla Chandra Ray was appointed Assistant Professor of Chemistry in the Presidency College, Calcutta, on a salary of Rs. 250 a month. He was quite satisfied with his teaching job.

His teaching skills made him popular with students. His lectures were marked by spicy humour. By introducing experiments and instances from everyday life he made the classes not only interesting but also inspiring. He would put a pinch of ash in his mouth to demonstrate that bones when cremated retained no trace of their animal origin but became mere chemical compounds. In later years, many of his students would admit that it was Ray's lectures that had inspired them to take to science. Famous Indian scientists, like Meghnad Saha and Shanti Swarup Bhatnagar, were among his students. Prafulla also used his knowledge of literature to good effect. He would recite poems of Rabindranath Tagore and quote slokas from *Rasa Ratnakara*, a book written by the ancient Indian chemist, Nagarjuna.

One thing that Ray felt strongly about was the use of the mother tongue as the medium of instruction in schools. He himself wrote science textbooks in Bengali. He told his students the story of the celebrated Russian chemist Mendeleev, famous for his Periodic Law, who published the results of his work in the Russian language. This compelled the scientists of other nations to learn Russian in order to read this important discovery. He also strongly believed that it was not enough for students to merely acquire degrees to get government jobs, but their real endeavour should be to acquire knowledge, through technical education and start their own business.

At first his own company The Bengal Chemical and Pharmaceutical Works, found it difficult to sell the chemicals it produced. Competition from imported chemicals was tough. But slowly, a chain of supporters grew around Prafulla's venture and started using the chemicals made by his firm. Many graduates in chemistry joined his factory and worked hard for it. Very soon The Bengal Chemical and Pharmaceutical Works became a name to reckon with.

It was not just his own venture that he promoted. With his active cooperation, direct or indirect, several textile mills, factories, industries, and publishing houses were set up. He was associated with establishments such as Bengal Potteries, Bengal Enamel Works, Calcutta Soap Works, National Tanneries and so on. With his inspiring dynamism Prafulla became the driving force behind the industrialization of the country that had just begun.

However, during all these years, Ray was also actively engaged in research in his laboratory at the Presidency College. His work on mercurous nitrite and its derivatives brought him worldwide recognition. He continued publishing scientific papers and guiding doctoral students.

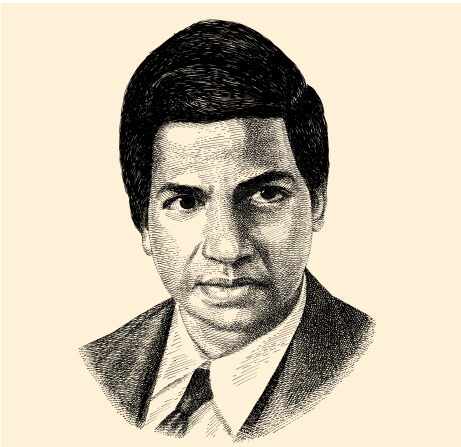
The *charkha* (the spinning wheel) and *khadi* movement started by Gandhiji had a great impact on Ray. Just like Gandhiji, he believed that the spinning wheel could become a good source of income for poor villagers. He began to spin yarn with the *charkha* at least for one hour everyday, wore only *khaddar* (Indian homespun clothes) and even earned the sobriquets *Charkhashri* and *Sir Khaddar* from his friends!

In 1916, Ray retired from the Presidency College but Ausutosh Mookerjee, the Vice- Chancellor of the University of Calcutta, appointed him Professor of Chemistry at the newly set up University Science College. He remained associated with the Institute for twenty years, finally retiring at the age of seventy-five. But even before his retirement, in 1921 he donated, in advance, his entire salary for the rest of his term to the Department he headed. He also set up two annual research prizes in Chemistry -- one named after the great Indian chemist Nagarjuna and the second after Ausutosh Mookerjee.

Throughout his life Ray never let go of any opportunity to do his bit for others. He had inherited his father's penchant for social service. In 1922, a great flood swept north Bengal and many were rendered homeless. He organized a relief committee which included leading European and Indian citizens of Calcutta. He made his college the centre of relief operations. With the help of his students and other citizens, he collected clothes and food as well as large sums of money for the needy. Impressed with his coordinated flood relief operations in Bengal, Gandhiji once called him a *Doctor of Floods*.

Ray also gave away his shares, valued at a 100,000 rupees in The Bengal Chemical and Pharmaceutical Works as an endowment. The profit from this endowment was used for the benefit of widows and orphans. The rest of his savings went to the Brahmo Samaj and in setting up a school in Ratuli village, in his father's name. He often shared his bachelor's accommodation with impoverished students.

The life of this great Indian scientist, the most part of which was spent in selfless service, finally came to an end on June16, 1944, in the same room that he had occupied for twenty-five years.



SRINIVASA RAMANUJAN

1887 -- 1920

When G. H. Hardy, was asked to rate the top mathematicians of his time on a scale of 100, he gave himself 25 marks, Littlewood got 30, Hillbert got 80, while Ramanujan got 100 upon 100. Such was the reputation that Ramanujan enjoyed among mathematicians of his time. In 1984, over hundred mathematicians and scientists contributed money for a bust sculpted by Paul Granlund, that was later handed over to his wife. Ramanujan left behind 4,000 original theorems, despite his lack of formal education and a short life span.

Srinivasa Aiyangar Ramanujan was born in Erode, in Tamil Nadu, on December 22, 1887. His father worked as a petty clerk in a cloth factory. After attending primary school in Kumbhakonam, he entered the Town High School in 1898. From early childhood it was evident that he was a prodigy and at the age of 13, he had already plunged into serious arithmetic and geometry. The turning point in his life came when he chanced upon the book *Synopsis of Elementary Results in Pure and Applied Mathematics*, by George Shoobridge Carr. The book contained theorems, formulae and short mathematical proofs. It also contained an index to papers on pure mathematics published in the European journals of learned societies during the first half of the nineteenth century. It was this book that triggered the mathematical genius in him. He discovered the relationship between circular and exponential functions.

From that moment onwards, Ramanujan's mind was flooded with mathematical ideas – and so many of them that he would solve the problems on loose sheets of paper and jot down the results in his notebooks. The notebooks would later become famous as Ramanujan's frayed notebooks. Even today mathematicians are studying them to prove or disprove those results.

After a first class in mathematics in the matriculation examination Ramanujan entered the Government College in Kumbhakonam in 1904. He was also awarded the Subramanyam scholarship. During that time Ramanujan was particularly interested in relations between integrals and series. In 1906, Ramanujan went to Madras where he enrolled at Pachaiappa's College. He failed twice in the first year arts examination, because he neglected other subjects such as history, English and physiology. Soon he fell ill and had to leave the college. Later, he sat for the examination and again passed only in mathematics.

In 1908, he fell seriously ill and in April 1909 had to undergo an operation. But even during his illness Ramanujan was driven by his passion for mathematics, always scribbling numbers. Fearing for his sanity, his parents married him off to S. Janaki Ammal, then only eight or nine years old, hoping that marriage would bring him around to the real world. But this only thrust upon him a responsibility he was not ready for. He began to look for a job but his unkempt and unimpressive visage did not get

him very far. Wherever he went he showed his frayed notebooks and told people that he knew mathematics and could do clerical jobs. No one could understand what was written in the notebooks and his applications were turned down.

In 1911, he approached Ramachandra Rao, Collector at Nellore and the founder-member of the Indian Mathematical Society. This is what Rao wrote about their first encounter, *A short uncouth figure, stout, unshaven, not over-clean, with one conspicuous feature--shining eyes, walked in with a frayed notebook under one arm. He was miserably poor. He ...began to explain.....but my knowledge did not permit me to judge whether he talked sense or nonsense...I asked him what he wanted. He said he wanted a pittance to live on so that he might pursue his research*. Rao tried unsuccessfully to arrange for a scholarship for Ramanujan.

Ultimately, Ramanujan did find what he was looking for, a clerical job. Francis Spring, the Director of the Madras Port Trust, gave Ramanujan a clerical job on a monthly salary of Rs. 25. Later, some teachers and educationists interested in mathematics who had seen Ramanujan's work, initiated a move to provide him with a research fellowship.

In 1913, Ramanujan sent a letter to G. H. Hardy, the renowned mathematician of Trinity College. He set out 120 theorems and formulae. He also gave a key formula in hypergeometric series, which came to be known after him. Hardy would have ignored the letter from an obscure Indian but as fate would have it, he glanced at the theorems included and was instantly hooked. As Hardy later said, *No one would have had the imagination to cook them up*. It did not take long for Hardy to realize that they had discovered a mathematical genius. Only a mathematician of the highest class could have written those theorems. Subsequent correspondence with Ramanujan was enough to convince Hardy that here indeed was a genius. He asked Ramanujan to come over to England and even made arrangements for Ramanujan's passage and stay at Cambridge University.

All through this eventful decade of Ramanujan's short life, the Madras University came to his help thrice. It offered him the first research scholarship of the University in May 1913; then it offered him a scholarship of 250 pounds a year for five years with 100 pounds for passage by ship and for initial outfit to go to England in 1914; and finally, it granted Ramanujan 250 pounds a year as an allowance for five years commencing from April 1919, soon after his triumphant return from Cambridge with a scientific standing and reputation such as no Indian has enjoyed before.

On March 17, 1914, Ramanujan sailed for Britain. But his decision to travel abroad was not without its usual share of drama, for it raised quite a few eyebrows in his family, as foreign travel by devout Hindus was frowned upon in those days. The story goes that the family deity, Goddess *Namagiri*, appeared in a dream and parental permission was subsequently granted for the voyage.

Ramanujan arrived in Cambridge on April 14, 1914 and found himself a total stranger there. Coming from the sunny climate of India, the English cold was hard to bear. Also, being a *Brahmin* and a vegetarian, he had to cook his own food. However, all through this hardship one factor remained constant--his interest in mathematics. And the company of Hardy and Littlewood made him forget much of his hardship.

During his five years stay in Cambridge, he published 21 papers, five of which were in collaboration with G.H. Hardy. His achievements at Cambridge included the Hardy-Ramanujan circle method in number theory and Roger-Ramanujan identities in partition of integers. He worked on composite numbers, algebra of inequalities, probability theory, continued fractions, and so on. Hardy always regretted that he had not chanced upon Ramanujan during the most fertile years of the latter's life which were spent battling poverty and neglect. Hardy also found Ramanujan an unsystematic mathematician.

In 1916 Ramanujan was awarded the B.A. degree by research of the Cambridge University. He was elected a Fellow of the Royal Society of London in February 1918. In October the same year he was

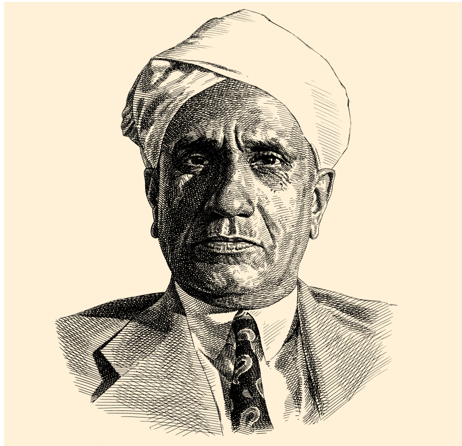
elected to a Trinity College Fellowship -- the first Indian to be elected Fellow of Trinity College. He received a prize fellowship worth 250 pounds a year for six years with no duties or conditions attached. But Ramanujan was not destined to live long enough to enjoy either fame or prosperity.

His health began to fail. Tuberculosis had begun devouring him. He spent a long time in hospitals. His mind, however remained razor sharp. Once, Hardy visiting him in the hospital mentioned that the number of the taxi he had come in was 1729, and that he thought it was *rather a dull number*. From his sick bed, Ramanujan protested, *No, Hardy, it is a very interesting number. It is the smallest number that can be expressed in two different ways as the sum of two cubes*. As usual he was right because 1729 can be written as 103+93 and also as 123+13.

Failing health forced Ramanujan to return to India. Hardy, his mentor wrote, *He will return to India with a scientific standing and reputation such as no Indian has enjoyed before, and I am confident that India will regard him as the treasure he is. His natural simplicity and modesty has never been affected in the least by success--indeed all that is wanted is to get him to realize he really is a success*.

His health may have deserted him but his passion for mathematics did not diminish in the slightest. Even on his deathbed he continued to play with numbers. It was a touching sight to see him lying in bed solving mathematical problems while his wife fed him rice balls with her own hands. On April 26, 1920, Ramanujan died, aged 32 years, at Chetpet in Madras.

Although Ramanujan had taken his notebooks with him to Cambridge, he had no time to delve deep into them. The 600 formulae he jotted down on loose sheets of paper during that one year he had in India after his return from Cambridge, are in the book *Lost Note Book* brought out by Narosa Publishing House in 1987, on the occasion of Ramanujan's birth centenary. The notebooks were found by George Andrews of Pennsylvania State University in the estate of G.N. Watson in the spring of 1976.



CHANDRASEKHARA VENKATA RAMAN

1888-1970

He is often remembered as the genius who won the 1930 Nobel Prize for Physics, working with simple equipment barely worth Rs. 300. Chandrasekhara Venkata Raman was one of the greatest experimental physicists of the century and the first Asian scientist to win the Nobel Prize. His spirit of inquiry and devotion to science laid the foundations for scientific research in India, for not only did he win honour as a scientist but also inspired several generations of students.

Raman was born on November 7,1888, in the town of Tiruchirapalli on the bank of river Cauvery, into a family of traditional agriculturists. It was a departure from family tradition when Raman's father, Chandrasekhara Ayyar, a scholar in physics and mathematics took to teaching in the local school. He loved music. Raman too, grew up in an atmosphere steeped in music, Sanskrit literature and science. His father took another bold decision when he accepted the post of lecturer in physics and mathematics at the A. V. N. College in the harbour town of Vishakhapatnam and moved there with his wife, Parvathi Ammal, and their four-year-old son, Raman.

The next ten years of Raman's life were spent in Vishakhapatnam at the high school and in college. He stood first in every class and his genius became evident, early on. He read far beyond his classroom level and when doubts arose, set down questions like 'How?' 'Why?' and 'Is this true?' in

the margin of textbooks. After his intermediate examination, he moved to Madras in 1903, and joined the B.A. class in Presidency College. In the year 1905, he was the only student who passed in the first class, also winning a gold medal in physics. In 1907, he took his M.A. degree, again obtaining a first division with a record score of marks.

While still a student at the Presidency College, he undertook original investigations in acoustics and optics and also wrote research papers for reputed science journals. The works of the German scientist Helmholtz and the English scientist Lord Rayleigh on acoustics, influenced Raman. When he was eighteen years old, one of his research papers was published in the Philosophical Magazine of England. Later, another paper was published in the scientific journal, *Nature*. At the age of nineteen, he became a member of the Indian Association for the Cultivation of Science.

However, since pursuit of science in India at that time offered little career opportunity, Raman joined the Indian Audit and Accounts Service (I.A.A.S.) standing first in the competitive examination. While he was waiting for the posting to come through he married Lokasundari Ammal on May 6,1907, a girl who proved to be a worthy and life-long companion, and one whose principal interest in life lay in doing all she could to enable to Raman to carry on with his scientific work, uninterrupted. In June 1907, he was posted to Calcutta as Assistant Accountant General in the Finance Department in which he spent the next ten years of his life. Fortunately, a great part of the time was spent in Calcutta, and it was in Calcutta that something happened to give a new turn to his life.

One evening, as Raman was returning from office in a tramcar, he caught sight of the signboard of the Indian Association for the Cultivation of Science (IACS) at 210, Bow Bazaar Street. He got off the tram immediately, and went in. Amritlal Sircar, son of the founder Mahendralal Sircar, was the Honorary Secretary of IACS. Raman walked through spacious rooms and found old scientific instruments, which could still be used for demonstration of experiments. He asked whether he could conduct research there in his spare time. Sircar gladly agreed. Raman moved to a house next door to the Association and a connecting door was opened between his house and the laboratory. During the daytime he attended office but his mornings and nights were devoted to research. The Association thus became his work place for many years.

Raman was transferred to Rangoon, the capital of Burma, in 1909. When his father passed away in 1910, he came to Madras on six months leave. After completing the last rites for his father, he spent the rest of his leave doing research in the Madras University laboratories.

Through his link with IACS, Raman had come in contact with Sir Asutosh Mookerjee who, as Vice-Chancellor of Calcutta University, was instrumental in establishing the University Science College in 1915. When Sir Asutosh wanted a professor to fill the newly created Palit Chair in Physics, he could think of none other than Raman and offered him the post. Well aware that the salary would be much lower, Raman quickly gave up his powerful post in the government all the same, and joined the Calcutta University as Palit Professor of Physics in 1917.

In 1919, after the death of Amritlal Sircar, Raman was elected Honorary Secretary of IACS. He now had the charge of two laboratories — of the College and of the Association. This gave a new stimulus to his research. Raman frequently referred to this period as the golden era in his career. Absorbed in experiments, it was not unusual for him to forget food and sometimes, working late through the night, he would sleep on one of the laboratory tables.

Students came to him from different parts of the country for post-graduate studies and research both at IACS and at the University College. Research workers like Meghnad Saha and S. K. Mitra, who became famous later, worked at these centres. According to the terms of the Palit Chair, he could have kept himself free from teaching work, doing only research. But Raman took immense pleasure in teaching and students were greatly inspired by his lectures.

Some of the areas that interested him at that time were, vibrations and sound; theory of musical instruments; optical studies such as diffraction, colours and interference; colloids; molecular scattering of light; X-rays; magnetism and magneto-optics.

Raman was a great lover of music and used to say, *I should live long, because I have not heard all the music I want to hear*. He was a frequent visitor to a musical instruments shop in Balepet, in Bangalore and collected a variety of musical instruments like the *mridangam*, the *tabla*, the *veena*, the violin and the *nagaswaram*. Around 1918, he had explained the complex vibrations of the strings of musical instruments. He later defined the characteristic tones emitted by the *mridangam*, the *tabla* and so on. Some years later, he was asked to contribute an article on the physics of musical instruments to the *Handbuch der Physik* and he did so for the eighth volume of that series, published in 1927. Few persons would know that he was elected to the Royal Society, London in recognition of his work on the physics of Indian musical instruments.

Raman loved colour, beauty, form, and rhythm in nature. He collected thousands of specimens of butterflies and purchased hundreds of diamonds of different forms. He was so bewitched by the physical properties of the diamond that at one time every researcher in his laboratories was working on the physics of this simplest of all crystal structures.

And then came Raman's discovery of the scattering of light that catapulted him to world fame. The Raman effect, as it is more popularly known, had its origin in the wonderful blue colour of the Mediterranean Sea. Lord Rayleigh had attributed the colour of the sea to the blue of the sky reflected by the water. In 1921, on his way to Oxford to attend the Universities' Conference by ship, Raman was struck by the deep blue opalescence of the Mediterranean water. On board the ship itself, he conducted some experiments using a nicol prism. Soon after returning to Calcutta, he carried out more experiments at his IACS Laboratory, with waters collected from different seas. He came to the definite conclusion that it was the scattering of light molecules by the oceanic waters that made them look blue. For the next seven years, Raman and his students carried out several experiments and established the various laws of molecular scattering of light in diverse media and 56 original research papers were published from Raman's laboratory.

Raman finally decided to clinch the issue and asked K. S. Krishnan to take up the experimental work on the anomalous scattering in liquids and vapours, in collaboration with him. While Raman was checking and confirming the results obtained by Krishnan, a joint letter was drafted and sent for publication to *Nature* on February 16,1928, which was published in its issue of March 31, 1928.

On February 28,1928, Raman had announced the discovery to the press and the public. On March 16,1928, Raman delivered an address to the newly formed South Indian Science Association at Bangalore, under the title: A New Radiation. He also acknowledged with affection the assistance given by K.S.Krishnan and K.Venkateshwaran, who were his students. Immediately on return to Calcutta, Raman had this address printed overnight at the Calcutta University Press and mailed the reprints to thousands of scientists all over the world. The phenomenon captured the attention of research workers all over the world. It became famous as the 'Raman Effect'. The spectral lines in the scattered light are now known as 'Raman Lines'.

Investigations, making use of the Raman Effect, began in many countries. During the first twelve years after its discovery, about 1,800 research papers were published on various aspects of it and about 2,500 chemical compounds were studied. The Raman Effect was perceived as one of the greatest discoveries of the third decade of the twentieth century. In 1929, the British Government conferred knighthood on Raman. And finally, in 1930, he was awarded the Nobel Prize in Physics. No Indian or Asian had received the Prize for Physics till then. At the ceremony for the award, Raman used alcohol to demonstrate the Raman Effect but later in the evening, when alcoholic drinks were served at the dinner, Raman did not touch them.

Raman left his indelible imprint on several institutes, some of which he had personally helped to set up. In 1933, Raman was appointed Director of the Tata Institute (later renamed Indian Institute of Science) at Bangalore. Under his able guidance and inspiration the Institute soon became famous for the study of crystals. In order to encourage scientific research in India, Raman established the Indian Academy of Sciences in 1934, drawing in distinguished and active scientists from various parts of India as its foundation fellows. The Government of the princely state of Mysore granted 24 acres of land free of cost to promote the activities of the Academy.

His earnest desire was *to bring into existence a centre of scientific research worthy of our ancient country, where the keenest intellectuals of our land can probe into the mysteries of the Universe*. It led him in 1948 to establish a Research Institute at Hebbal, Bangalore. He gave away all his property to the Institute that later came to be known as the Raman Research Institute. At the Institute, he wished to concentrate on things that interested him and the entrance displayed a board bearing the words, *The Institute is not open to visitors. Please do not disturb US.*

In 1954, Raman was bestowed with the greatest honour the Government of India confers on an Indian -- the Bharat Ratna.

During the last few years of his life Raman became increasingly isolated from other scientists in India. He was generally critical of the post-Independence scientific efforts in India and disapproved of young scientists leaving India to build their careers. Raman wanted the young persons working with him to take up independent positions and to serve the nation. He saw his laboratory as a centre for training young talent, not a permanent storehouse.

Towards the end, Raman became an Institution in himself and work was all that mattered to him. He never dreamt of a life without work. He had told his doctor, *I wish to live a hundred per cent active and fruitful life*. Every year he used to deliver a popular science lecture on the occasion of Gandhi Jayanti. On October 2,1970, he spoke on the new theories about hearing and the eardrum. This was his last lecture. After a short illness he passed away on November 21, 1970.



SISIR KUMAR MITRA

1890-1963

Remembered for his contributions to the development of broadcasting in India, it was Sisir Kumar Mitra who started the radio industry in the country. Mitra specialized in radio physics, wireless and industrial research. It was due to his untiring efforts that radio science gained importance as a subject and began to be taught in Indian universities.

Mitra was born at Konnagar, a suburb of Calcutta, on October 24,1890. He was the third son of Joy Krishna Mitra, a school teacher. His mother, Sarat Kumari, who had been trained at the Campbell Medical School in Kolkata, obtained a post in the Lady Dufferin Hospital in Bhagalpur and the family moved to that town. And so it was that Mitra first went to school in Bhagalpur. When he was a young boy, he witnessed a man called Ram Chandra Chatterjee demonstrate how one could ascend by balloon. Not getting a satisfactory answer from his elder brother, he began looking for the answer in science books and magazines. In due course he came across the writings of J. C. Bose. This was the beginning of his interest in science.

But then tragedy struck. His two elder brothers died and his father became paralysed. Had it not been for the insistence of his mother that he continue his education, Mitra would have had to leave school. After clearing school and college from Bhagalpur he managed to secure admission in 1908 to the Presidency College, Calcutta, where in 1912 he headed the list of successful candidates for the M.Sc. degree in Physics. At the Presidency College he had the privilege of watching closely J. C. Bose and P. C. Ray doing research. In fact, Bose's pioneering equipment for generating and detecting radio waves influenced him to take up research in radio science. In 1916, it was an offer for the post of lecturer at the newly formed postgraduate Department of Physics of Calcutta University that marked the beginning of his scientific career.

In 1919, after being awarded the D.Sc. by Calcutta University for his thesis on the *The Interference and Diffraction of Light*, he went to work under Professor Fabry, at the Sorbonne. He obtained his Doctorate degree there in 1923, and then worked for some time at the Institute of Physics in the University of Nancy, where he studied the behaviour of thermionic valves. He also came across scientists carrying out research on radio frequency oscillations in discharge tubes. It was then that he decided to change his line of research and study the propagation of radio waves.

In 1923, Mitra was offered the Khaira Chair of Physics in the University of Calcutta where he started to teach wireless at the postgraduate level. Soon afterwards, a wireless laboratory was set up in 1925. For years to come, this laboratory would provide facilities for researches on electron tubes and propagation of radio waves. Next, Mitra constructed a radio transmitting station in the laboratory with the call sign 2CZ. Along with other amateurs in Bombay and Madras, this station in Calcutta broadcasted regular programmes for general reception. It was not until the Indian Broadcasting Company started transmissions in 1927, that 2CZ was closed down. 2CZ proved to be a valuable training ground in radio and electronic techniques for future engineers in broadcasting organizations.

In scientific circles, Mitra is renowned for his contributions to the study of the ionosphere. The ionosphere is composed of several layers designated as D, E, F and so on. Based on his researches Mitra found that the ultraviolet radiations emitted by the sun produced the E layer. This was a wonderful achievement as the presence of this layer had baffled scientists the world over.

Mitra also found out why the night sky appears dusty black and not jet-black, as it should. He attributed this to the presence of ions in the F layer which emit some light, the process being called night sky luminescence.

In 1935, Mitra was appointed to the Ghosh Chair of Physics, which he held until his retirement. On a visit to England and the United States in 1944 he was impressed by the manner in which radio and electronics were being taught in the universities. Back home, Mitra worked tirelessly until he succeeded in establishing a new Institute of Radio Physics and Electronics in 1949. Mitra became the first head of this Institute. In 1952, the Institute was transferred to a new building and in 1955, a separate Ionospheric Field Station was set up in Haringhata.

Setting up just one station was not enough. Mitra realized that observatories ought to be set up in more places other than Calcutta, if a fruitful synoptic study of the ionosphere was to be made in India. He worked hard at realizing this goal until a Radio Research Committee was finally set up in 1943 and Mitra became its first Chairman, a post he held until 1948.

Mitra was acclaimed in international scientific circles for his book *The Upper Atmosphere*. The book was written with the help of an enthusiastic team of research workers. But none of the European or American publishers were ready to publish it. Eventually, M. N. Saha, who was then the President of the Asiatic Society of Bengal, persuaded the Society to bring it out as one of its memoirs. The book was published in 1947 with a printrun of 2,000 copies, which were sold out within two years. A

revised edition was published in 1952. Mitra's reputation in international circles rests on this book.

In 1955, he retired from the University and relinquished the Ghosh Chair of Physics. In 1956, he was appointed Administrator of the Board of Secondary Education in West Bengal, a post he held until 1962, when he was appointed a National Research Professor by the Government of India. He was General Secretary of the Indian Science Congress Association (1939-1944) and was elected its General President in 1956.

Those who had the opportunity of knowing Mitra well in India held him in high regard because of his devotion to duty, his meticulous observance of rules and regulations, and his concern for precision and perfection in speech and writing. During his lifetime Mitra won several awards. He was elected to the Fellowship of the Royal Society in 1958 and in 1962, he received the Padma Bhushan.

An attack of cardiac asthma took the life of this great Indian scientist on August 13,1963 in Kolkata.



BIRBAL SAHNI

1891-1949

In 1932, Sir Philip Hartog came to Lucknow to meet Birbal Sahni, then already a renowned palaeobotanist. As he was being shown round the Botany Department, he casually asked, *Where does Professor Sahni work?* On being shown a table in the corner of the botany museum he exclaimed, *What! Professor Sahni has no room of his own?* Then he added smilingly, *Yes, great scientists have worked only in garrets.*

That was a glowing tribute to Birbal Sahni, the most eminent palaeobotanist India has ever produced and the man who pioneered research in palaeobotany in India. He founded the Institute of Palaeobotany at Lucknow in 1949 the only one of its kind in the world, now named after him. So intense was his love for the subject that he donated his entire life's savings for setting up the Institute.

Sahni was born on November 14, 1891 at Bhera, now in Pakistan, into a family which was unusually enlightened, and which held education in high esteem. His father, Lala Ruchi Ram Sahni, was a scholar. He encouraged the boy to collect plants, rocks and fossils, and during vacation time took him to the Himalayan mountains and other places.

Birbal had his early education at Lahore, first at Mission and Central Model Schools and then at the Government College. After obtaining the B.Sc. degree from the University of Punjab in 1911, he travelled to England and entered Emmanuel College, Cambridge. Graduating from Cambridge in 1914, he settled down to research at the Botany School where he came under the spell of A.C. Seward. The years that he spent under Seward's tutelege were the most fruitful ones of his life. Sahni always had the greatest regard and affection for his master and in many ways he seems to have taken Seward as his model.

Sahni began his research work at Cambridge with conventional investigations of morphology and anatomy of living plants, but before long he took up the study of fossil plants. He published his first paper in the *New Phytologist* entitled *On the presence of foreign pollen in the ovules of Gingko biloba, and its significance in the study of fossil plants*. For his researches on fossil plants he was awarded the D.Sc. degree of London University in 1919. The University of Cambridge recognized his work by the award of ScD. in 1929, said to be the first such award to an Indian scientist. Seven years later, he was elected a Fellow of the Royal Society, London.

Sahni's first introduction to the rich stores of fossil plants in India was in 1917 when he joined

Seward in the production of a *Revision of Indian Gondwana Plants*. This work dealt with gymnosperms of varied types. In 1919, after working for a short period at Munich under the renowned German plant morphologist Goebel, Sahni returned to India. He held the Chair of Botany at the Banaras Hindu University for one year and for another year was Professor of Botany in the University of Panjab.

In 1920, he married Savitri Suri, younger daughter of Sunder Das Suri, Inspector of Schools in Punjab. His marriage was a happy one, for his wife took very active interest in all his work and was his life-long companion.

The turning point in Birbal Sahni's life came in 1921 when he took charge of the newly opened Botany Department of Lucknow University as Professor. He undertook, with great energy and enthusiasm, the work of organizing the department and of providing teaching on the same plan as at Cambridge. Very soon, he had established that apart from being a keen researcher, he was also a teacher par excellence. A former student of his had this to say about him: *Professor Sahni always believed that the junior classes should be handled to a certain extent by their seniormost teachers. So he always insisted on his lecturing to the B.Sc. classes and sharing the undergraduate class practical work also, along with junior members of the staff*. He wrote a *Textbook of Botany* with Lowson which was used the world over.

Sahni's lectures to the undergraduate classes were exceedingly simple in style and direct in approach—at first stressing on the obvious and the important and then filling in details. But he never missed telling them briefly about the latest developments nor failed to refer to work in progress in India. In the practical classes too, he rarely left the room but was always busy correcting drawing books, explaining some difficult point or giving some tips about methodical and accurate practical work.

His reputation as a teacher and his fame as an investigator attracted students from all over India. Gradually, he became surrounded by a band of young and enthusiastic research workers. But Birbal Sahni had long realized that a student of botany cannot do justice to paleobotanical studies without adequate background of geology. He always kept in mind the geological background and implications of plant fossils that he chanced upon in the course of his excursions. He believed that "fossil plants represent the debt that botany owes to geology". At the same time, he also believed, and demonstrated too, that palaeobotanical research can not only be of considerable help in solving stratigraphical problems but also throw light on past climates and earth movements and thus contribute to economic geology.

It was this belief that led Sahni to make untiring efforts to set up a Department of Geology at Lucknow University in 1943. He became its first Head and taught dynamic geology and palaeobotany. He also gave introductory lectures on stratigraphical geology to the postgraduate students before they started their regular morphology course. He did more than anyone else to convince the geologists that study of plant fossils yielded results of a far-reaching nature that the geologist could not afford to ignore.

Among Sahni's more important discoveries was the recognition of a type of gymnospermous plants of Jurassic age, which Sahni named the Pentoxyleae, and which attracted worldwide attention. One of the problems that occupied much of Sahni's research career was the revision of the Indian Gondwana plants. Geologists had long established, on the basis of fossil records, that the Indian subcontinent was originally part of a supercontinent comprising South America, Africa, India, Australia and Antarctica. They named this supercontinent Gondwanaland after the Indian kingdom from where fossil plants, typical of all these continents some 300 million years ago, were first described. The most abundant among these plants were the *Glossopteris* type, the fossils of which were discovered in India. It was earlier believed that the *Glossopteris* plants were quite adapted to growing in a very cold glacial climate. But Sahni demonstrated with his fossil studies that the presence of *Glossopteris* indicated not glacial but cold temperate conditions.

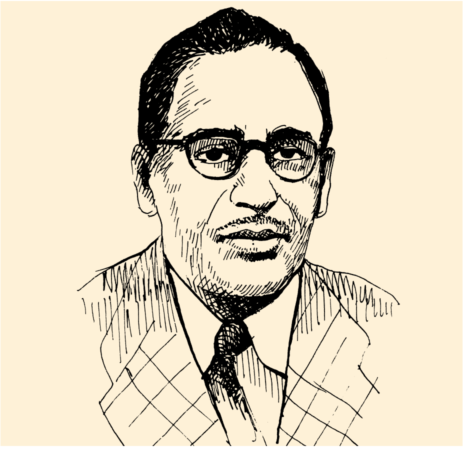
He also explored the Rajmahal Hills of Bihar, which is a treasury of plant fossils. From detailed studies of plant fossils found in the region he came to the conclusion that the Gondwana flora was *Jurassic* (geological period lasting from about 213 to 144 million years ago) with not a single species characteristic of the Cretaceous (geological period lasting from about 144 to 70 million years ago).

The reconstruction of past flora, on the basis of plant parts often found scattered in fossil beds at different times, is an exciting aspect of palaeobotany. Sahni had an uncanny ability to hunt up and fit together scattered fragments of one and the same stem or a leaf and a stem. One of the most well-known reconstructions done by Sahni was that of a cycad-like plant, fossils of which were discovered near Amrapara in Santhal Pargana district of Bihar. Fossilized stem, leaves and flowers of the plant had already been studied by other workers who had described each of them as belonging to a different group. But Sahni's own investigations convinced him that the flower and the leaves and stem earlier described, all belonged to the same plant. He named the plant *Williamsonia sewardiana*, in honour of his guru A. C. Seward who, in 1900, had first described the leaves of the plant from Rajmahal fossils. Sahni's investigations also led to the reclassification of a new genus and species of a cone-bearing plant with fern-like leaves which has been named *Pentoxylon sahnii* after him.

Sahni travelled widely and made himself popular wherever he went. He also took active part in the promotion of science in India. He was one of the founders of the Indian Botanical Society and was its President in 1924. The Royal Asiatic Society of Bengal awarded him the Barclay Medal for biological research and he received the Sir C. R. Reddy National Prize for Natural Science in 1947.

In 1929, he had conceived the idea of establishing a central Indian museum for fossil plants. However, lack of official encouragement saw his idea wither away. But during the last ten years of his life, he relentlessly pursued another idea—that of establishing an institute devoted to palaeobotany. Birbal Sahni and his wife provided most of the funds, contributions from various donors were added from time to time, and grants were received from the Government of India and from the Provincial Government of Lucknow. A governing body was set up and the work of the Institute was begun in the Department of Botany and Geology in the University of Lucknow. Soon a piece of land could be secured for the Institute's own building. On April 3, 1949, Jawaharlal Nehru laid the foundation stone of the Institute of Palaeobotany. The foundation stone was itself quite unique. Designed by Sahni himself it was a mosaic of plant fossils collected from various continents of the world.

Tragically, Sahni did not live to see his dream come true. Five days after the foundation-laying ceremony, he succumbed to a severe heart attack. The legacy that Birbal Sahni left behind continues to inspire generations of palaeobotanists even today.



MEGHNAD SAHA

1893-1956

Fearless and frank in his criticism of government policies, imbued with the spirit of nationalism and self-sacrifice, so much so that when the British Government divided Bengal in 1905, a 12-year-old schoolboy boycotted the Governor's visit. He paid a heavy price with his name being struck off the school rolls. The boy grew up to become an astrophysicist of world repute whose theories of thermal ionization of

elements and selective radiation pressure revolutionized astrophysical thought. That was Meghnad Saha, one of the foremost scientists that India has produced and one who not only raised the status of science in independent India but also served the cause of the poor.

Meghnad was born on 6 October 1893 in Seoratali village of Dacca district, now in Bangladesh. He was the fifth child of his parents Jagannath Saha and Bhubaneshwari Devi. His father was a petty grocer who barely managed to feed his large family. Meghnad, therefore, worked for some time at his father's shop even as he pursued his education in the village primary school. His father wanted the boy to start earning for the family from his very childhood, but some teachers who recognized his calibre early on, persuaded his father to allow him to continue schooling beyond the primary stage.

Reluctantly, his father arranged for his son to be sent to an English school 11 kilometres from the village. Meghnad's eldest brother, who took a great deal of interest in his education managed to persuade Ananta Kumar Das, a local medical practitioner, to let Meghnad stay in his house, free of board and lodging. He would never forget the help and kindness of Das at the start of his educational career. Meghnad stood first in the middle school examination and was awarded a scholarship which enabled him to get admission to the Collegiate School in Dacca in 1905. And then came the boycott episode, after which his name was struck off the rolls of the school and he had to forfeit his scholarship as well. Meghnad was then admitted to the Kishori Lal Jubilee School with a free studentship with his brother chipping in with the remaining expenses. In 1909, he passed the Entrance Examination standing first among those who appeared from East Bengal.

After passing the Intermediate Examination from the Dacca College he won a scholarship and joined the Presidency College in Kolkata. Here he was not only taught by eminent teachers like J. C. Bose and P. C. Ray, but also had brilliant contemporaries like S. N. Bose, P.C. Mahalanobis and Nil Ratan Dhar. He also made the acquaintance of Subhash Chandra Bose who was three years his junior, two of his older brothers being Meghnad's classmates.

Meghnad secured the second position in first class both in B.Sc. in mathematics and in M.Sc. in applied mathematics. He thought of competing for the Indian Finance Examination but was not allowed to appear because of his association with revolutionaries like Jatindra Nath Mukherjee, Pulin Das and Subhash Chandra Bose. With all hope gone of a government job, he decided to carry on research in applied mathematics and physics. He also took on the responsibility of educating his youngest brother. He would earn money by giving tuitions morning and evening, cycling to distant places, to support himself and his brother.

In 1917, Sir Asutosh Mookerjee was looking for exceptionally talented persons to man the newly created postgraduate departments in science at the University College of Science in Calcutta. He invited Meghnad Saha and S. N. Bose to join the Department of Mathematics. But since these two could not get along with the Ghosh Professor of applied mathematics, both were transferred to the Department of Physics with Sir Asutosh Mookerjee's permission. Without the guidance of any senior professor Saha plunged heart and soul into theoretical and experimental researches in physics. Very soon he had published original papers in noted journals of physics, like the *Philosophical Magazine* of London and the *Physical Review* of USA. On the basis of these papers he was awarded the D.Sc. degree by Calcutta University in 1918.

Meghnad Saha's claim to fame rests on his theories of thermal ionization of elements, and of selective radiation pressure. Saha had been intrigued by one problem of astrophysics as he pored over books to prepare for his lectures. The spectrum of sun's chromosphere had been observed by Lockyer and Jansen as early as 1868. Gustave Robert Kirchoff had shown that the spectral lines comprising the spectrum told of the elemental composition of the sun, but astronomers could not make out what caused them. Saha put forward an ionization formula that explained

the presence of the spectral lines. The formula also enabled an astronomer to arrive at the temperature, pressure and several other aspects of the interior of the sun or any other star. The formula proved to be a breakthrough in astrophysics and very soon made him internationally famous. An eminent astronomer even called it the twelfth major discovery in astrophysics. Almost a decade after his discovery, Saha was elected a Fellow of the Royal Society, London.

The very next year he was awarded the Premchand Roychand studentship that enabled him to set out on a two-year study trip to Europe in September 1919. On his arrival in London he found that the funds he had were inadequate for a sojourn in Oxford or Cambridge. At the suggestion of one of his friends, Saha joined Fowler's spectroscopy laboratory at the Imperial College of Science and Technology, London. Working in Fowler's laboratory, he acquainted himself with the rapid advances in the classification of spectra which were taking place in Germany and England. He also discussed his theory of thermal ionization with Sir J.J.Thomson. During his stay in London he met S.S.Bhatnagar for the first time. Their acquaintance soon ripened into a close friendship. Saha would call him 'Steam Ship Bhatnagar' for his extraordinary energy.

Later, Saha worked for about a year in Nernst's laboratory in Berlin. It was during his stay in Berlin that he received an invitation from Sir Asutosh Mookerjee to return to the Calcutta University where a new Khaira Chair in physics had been created. On his return from Europe in 1921 Saha joined the post but it turned out to be a great disappointment. Sir Asutosh had a showdown with the Bengal Government and could not give Saha either a laboratory or an assistant.

Saha received offers from the Aligarh Muslim University, Banaras Hindu University and the Allahabad University. He chose Allahabad but things were not very smooth for him there either, to begin with. His colleagues were not cordial, nor were there sufficient grants to improve the laboratory. It was only after 1927 when he was elected a Fellow of the Royal Society that things began to happen. The Governor of the Province was pleased to make a research grant of Rs. 5,000 per year as personal recognition and Saha soon managed to establish cordial relations with his colleagues as well.

While at Allahabad, Saha showed brilliance as a teacher. He built one of the finest departments of physics, shouldering the responsibility of teaching frontier areas, like spectroscopy, X-rays and wireless. His lectures were famous, not only for the mastery of exposition but also for the large number of carefully designed demonstrations of experiments. In a few years' time Allahabad's contribution to physical science which had been negligible, began to rise with new life, as young researchers gathered around Saha from all parts of the country. Very soon the Department of Physics at Allahabad University gained international status.

One of Saha's achievements at Allahabad was the foundation of the UP Academy of Science in 1931, which was later renamed The National Academy of Sciences, India in 1934. Sir Malcolm Hailey who took a great interest in the inauguration of the Academy, sanctioned a sum of Rs. 4,000 per year for the Academy at Saha's request, in spite of the economic depression of 1931.

Saha returned to Calcutta in July 1938 as Palit Professor of Physics in the University College of Science and Technology. His reputation was at an all-time high. The subject that he chose for himself was nuclear physics. Otto Hahn discovered nuclear fission in 1939 and Saha at once realized its tremendous possibilities. He founded the Department of Nuclear Physics at Calcutta University, which in 1948 grew into the Saha Institute of Nuclear Physics. It was the fruit of Saha's genius and industry.

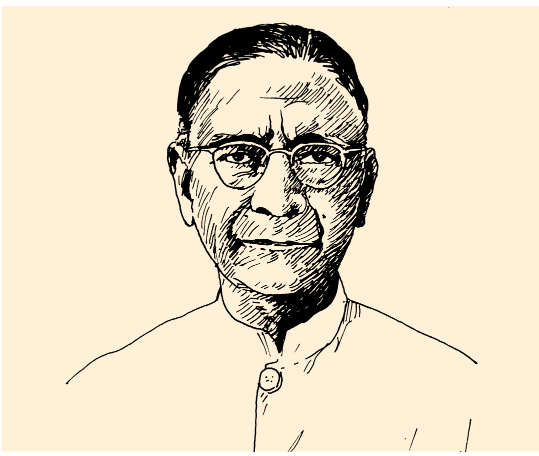
Saha is also remembered for his extensive studies on the origin and control of floods. He wrote a series of essays on floods, river management, irrigation and allied topics. In fact, a number of river valley projects, such as the Hirakud, Damodar Valley and Bhakra-Nangal projects, are the result of the work that he started. He was the chief architect

of the Damodar Valley Project which he had proposed in considerable detail in 1944.

Saha's intellect also did not fail to notice the mismanagement at every conceivable level. He wrote numerous articles based on an in-depth study of developmental plans of several countries, he also exposed the critical lacunae in our Five Year Plans. Critical of the neglect of the problem of population he observed, *In an overpopulated country like ours, the rate of population growth should be kept down as far as possible...It does not appear possible that the government can take much of an active step in this direction except by propaganda and education*.

As a young man, Meghnad had seen flood disasters and poverty at first hand. His heart bled for the sufferings of the common man. He would often organize relief work, whether it was for flood victims or for refugees uprooted as a result of communal disturbances. For days on end, he would work tirelessly visiting the refugee camps and making plans for their relief and rehabilitation.

This great scientist and planner who had a deep concern and vision for his country died on February 16, 1956.



P. C. MAHALANOBIS
1893-1972

The breathtaking beauty of Taj Mahal is a delight to behold. But if you happen to lay your hands on a guide written by India's best-known statistician, perhaps you may be able to appreciate its architecture still better. Prasantha Chandra Mahalanobis was the first Indian statistician to receive world recognition. In fact, the history of statistics in India reads more like Mahalanobis's biography.

Prasantha was born into a well-established family in Calcutta on June 28, 1893. His father had a flourishing business dealing in sports goods and his shop was a very popular rendezvous of athletes and sports lovers. His mother Nirodbashini was the sister of Sir Nilratan Sircar, a famous physician, educationist and industrialist. The family was imbued with liberal *Brahmo Samaj* traditions and had close contacts with the great intellectuals and social reformers of Bengal. All this had a deep influence on the young Prasantha and, in a way, prepared him for the active life he was to lead for seventy-nine years.

He passed the Entrance (later called Matriculation) examination from the Brahmo Boys School in Calcutta in 1908. After passing the Intermediate Science Examination in 1910 and the B.Sc. examination in 1912 from Presidency College, Prasantha left for London in the summer of 1913 to study for B.Sc. But as chance would have it, one day while on a visit to a friend at Cambridge, he missed the last train and stayed overnight with a friend. M. A. Candeth, an Indian undergraduate at King's College happened to drop by. Mahalanobis told him how deeply impressed he had been with the Chapel at King's. Candeth suggested that he should try to get into King's College. The very next day, an interview with Provost James ensured for him a seat at King's College. In 1914, he took Part I of the Mathematical Tripos but changed over to Physics and passed the Natural Science Tripos, Part II, with a first class in 1915.

Prasantha was no bookworm. He actively participated in social and cultural events, group discussions, the university union and was also fond of cross-country walks. He also had occasion to spend time with the great Indian mathematician Ramanujan.

After finishing his Tripos in physics, Prasantha arranged to work with C. T. R. Wilson at the Cavendish Laboratory, Cambridge. As the vacations approached, he planned to leave for India. But World

War I was on and there was some delay in starting his journey. One morning, while browsing in the King's College library, he chanced upon W. H. Macaulay who drew his attention to some bound volumes of *Biometrika*. On reading it, Mahalanobis was so thrilled that he brought along several volumes of the journal when he came to India for his vacation. He read the volumes on the boat during his journey, studied and worked out exercises on his own, during his spare time in Calcutta, and saw that statistics was a new science connected with measurements and their analysis, and capable of wide application. He tried to look for problems where he could apply the new knowledge. He found some interesting problems in meteorology and anthropology. It was this brush with statistics that would later become a life-long passion for him.

Another event that changed Mahalanobis's life forever was the World War. He decided not to go back to Cambridge to join the Cavendish Laboratory during war time, so he took up a lecturership in physics at Presidency College in Calcutta. But in spare time, he continued with studies in statistics. Many people thought that he was wasting his time. Statistics was known in India only in the sense of official data. The universities, research institutes or academic bodies did not recognize it as a separate discipline. Even the government bureaucracy was averse to introducing new methods or making changes in the existing practices. Mahalanobis had a great struggle ahead to advance the cause of statistics in India.

But there were three persons who realized the importance of the discipline and encouraged him—Rabindranath Tagore who had known him from childhood, Sir Nilratan Sircar, his maternal uncle, and Brajendra Nath Seal, Professor of Philosophy at Calcutta University, one who had himself, in his younger days, made original researches in mathematics. Seal took a personal interest in the statistical studies of Mahalanobis and predicted that one day statistics would become a basic scientific tool.

Another person who stood by him was his wife Nirmal Kumari, daughter of a great educationist and leader of the *Brahmo Samaj* movement. Soon after Mahalanobis returned from abroad, he fell in love with Nirmal Kumari and married her on February 27,1923. Though herself a strong-willed person, Nirmal remained a devoted wife and a constant companion to Mahalanobis throughout his life, accompanying him on his frequent tours abroad and within the country.

Mahalanobis did not consider statistics as a narrow subject confined to the mathematical theory of probability, or routine analysis of data in applied research, or collection of data as an aid to administrative decisions. He took a wider view of statistics as a *new technology for increasing the efficiency of human efforts in the widest sense*. Mahalanobis successfully applied statistical principles to problems in subjects, like anthropology, epidemiology, demography and meteorology. Impressed by his successes, various authorities approached him with their problems. For instance, in 1922, engineers attributed a disastrous flood that hit North Bengal to a rise in the river beds and advised the government to raise the embankments. When Mahalanobis was consulted he arrived at a different conclusion, using the figures of rainfall and floods for the past 50 years. He told the authorities that a better drainage system was required to ensure a smoother flow of the rivers. He did a similar study of floods in Orissa. The Hirakud hydroelectric project and the Damodar Valley multipurpose hydroelectric project are both based on his statistical studies.

These initial successes gave birth to the idea of starting the Indian Statistical Institute. The idea was mooted by Mahalanobis and a group of young persons in the 1920s, who were interested in applying statistical methods to the solution of practical problems. The Institute started as a workshop called the Statistical Laboratory which was located in Mahalanobis's room, who was then professor of physics at the Presidency College. On April 28, 1932, the Indian Statistical Institute (ISI)

was registered as a non-profit society under the Societies Registration Act.

To begin with, the Institute had only one part-time computer and the yearly expenditure was Rs. 228. *Sankhya*, the Indian Journal of Statistics was started in 1933,of which Mahalanobis was the editor. Among the first problems the Institute took up was developing a new technique of estimating acreage and yield of crops in a large region by random sampling and applied it to the jute crop in the province of Bengal in 1937. The first Indian Statistical Conference was organized by the Institute in 1938. Postgraduate studies in statistics were opened for the first time in Calcutta University in 1941 with Mahalanobis as the head of the Department. A central statistical unit was established by the Government of India in 1949, to work under the technical guidance of Mahalanobis. Two years later a Central Statistical Organization was formed for coordinating all statistical activities of the government and a few years later a new Department of Statistics was created.

In 1949, Mahalanobis became the Chairman of the Indian National Income Committee. He helped fill gaps in information for computing national income and in 1950, he established the National Sample Survey for the collection of socio-economic data through sample surveys covering the entire country. In 1954, the then Prime Minister of India called on Mahalanobis to initiate studies in Planning at the ISI to help in the formulation of the Five-Year Plans for he realized that the models suitable for developed countries might not be applicable for developing countries. In 1959, the ISI was declared as an institute of national importance empowered to award degrees by the Parliament. The Indian Statistical Service started in 1961. Within a short span of time, with his untiring efforts and meticulous organization Mahalanobis was able to raise statistics to a high pedestal. Some also call this period the Mahalanobis era in statistics.

Several of Mahalanobis's contributions to statistics such as *Mahalanobis distance* and *fractile graphical analysis* have been included in textbooks. Mahalanobis was elected a Fellow of the Royal Society, London, in 1945.

Mahalanobis remained active almost to the last day of his life. He was mentally alert and physically strong. He could spend long hours arguing or discussing with his colleagues even to the point of tiring them out. This visionary and the best-known statistician of India died in 1972 at the age of 79.



S. S. BHATNAGAR

1894-1954

When Shanti Swarup Bhatnagar died, the eminent Indian statesman C. Rajagopalachari stated that but for Bhatnagar, India would not have been so organized in its scientific efforts. Bhatnagar was an institution builder, who played a remarkable role in the development and management of scientific research in the country. The Council of Scientific and Industrial Research (CSIR), which he set up almost single handed, today spans a network of nearly 40 laboratories spread throughout the country. An eminent scientist and also a poet in Urdu, Shanti Swarup Bhatnagar was truly a man of many parts.

Bhatnagar was born on February 21, 1894, at Bhera in Shahpur district in Punjab. His father, Parmeshwari Sahay Bhatnagar, was a distinguished graduate of the Panjab University. His mother, Parvati, was the eldest daughter of Pearey Lal who was one of the first engineers to graduate from the famous Roorkee College.

But Shanti Swarup had a troubled childhood. His father lost his share of the family property and was disinherited because he had embraced *Brahmo Samaj*, and when he died he left his wife and young children in dire poverty. Parvati left Lahore with her two-year-old daughter and eight-month-old son, Shanti, and went to live with her father in Sikanderabad. It was here that Shanti developed a taste for engineering and science under the influence of his grandfather who had become a distinguished engineer and was employed in railway construction work. From an early age he became interested in his grandfather's instruments, Euclid and algebra, and in making mechanical toys.

Shanti's earliest schooling was in a private *maktab* which he joined in 1901 after which he studied in A. V. High School till 1907. In 1908, while attending a wedding, he had a chance encounter with Bishwanath Sahai, a science graduate from Lahore, and impressed him with his keen intellect. Back home, Bishwanath reported Shanti's prowess to his father Lala Raghunath Sahai who was the headmaster of Dyal Singh High School at Lahore. As it turned out, he learnt that young Shanti was the son of a close friend and former classfellow. He found young Shanti especially good in literature and sciences and persuaded his mother to send Shanti to the Dyal Singh High School. This was the turning point in Shanti's life.

The headmaster who later became his father-in-law was a great inspiration during that formative period. No sooner had he joined the school than Shanti secured a high-school scholarship in open competition and went on to earn his living by teaching young boys privately. Under the guidance of his science teacher, Moulvi Talib Ali Paband, he would often experiment with gadgets. As early as 1911, young Bhatnagar published a letter in *The Leader* of Allahabad on a method of making substitute carbon electrodes for a battery by heating molasses and carbonaceous matter under pressure. Later, as a scientist in 1942, in one of the CSIR laboratories, he developed a process for carbon electrodes in which indigenous materials were employed to meet the shortage of imports during the War.

Matriculating in the first division and securing a university scholarship Bhatnagar joined the Dyal Singh College in Lahore in 1911. Soon he was collaborating with N. N. Godbole on the *Fermentation Phenomenon of Pomegranate Juice* and published the results in *Raushni*, journal of the Society for Promoting Scientific Knowledge launched by Lahore Medical College students.

While still at college, Bhatnagar became an active member of the Saraswati State Society which was launched by Norah Doyle Richards, a London stage actress who had come to India as the wife of an English teacher. Encouraged by her, Bhatnagar became an amateur playwright in Urdu and wrote a one-act play called *Karamati* (Wonder Worker). The play satirized a miracle maker humbled by modern medicine. Bhatnagar played a caricature of himself in the play. The play was translated into English and he was awarded a medal of the Saraswati Stage Society for the best play of the year 1912.

When Bhatnagar passed the intermediate examination of the Punjab University in 1913 in the first division, Welinker, Principal of Dyal Singh College, wrote, *Mr. Shanti Swarup was one of the ablest students in that large class of about 100 students; indeed I am of the opinion that in all-round ability he was the ablest. He is a young man of more than usual ability and I feel sure that if he is given opportunities of developing talent in some great European or American centre of scientific research he will do some remarkable work in science and will thus be in a position to render high service to his country*.

Bhatnagar joined the Forman Christian College for a B.Sc. degree but was failed by the examiner. He had written in the physics paper that X-rays can be reflected, refracted and polarized like light. This was the latest finding of researches that he had read in journals, but it contradicted what was stated in Mellor's textbook. Not anticipating the setback, he had married Lajwanti, daughter of his school headmaster, during the vacations. He

had to take the B.Sc. degree all over again and to support himself and his wife, he again took up private tuitions. He also earned some money by developing a substitute for the German hektographic pad supplies that had been cut off by the War so that a local stationer could operate his duplicating machines.

Ruchi Ram Sahni took a special interest in Bhatnagar and was largely responsible for the award of a scholarship from the Dyal Singh College Trust for his studies abroad. Bhatnagar sailed for America from Bombay in August 4, 1919. When he reached England he found that all tickets for America had been booked for the American troops which were then being demobilized. Bhatnagar asked permission from the Trustees of the Dyal Singh College to do his post-graduate research in England and they agreed. He presented himself at the Ramsay Laboratory of F. G. Donnan, of the University College, London. Donnan set him a problem and satisfied enough with Bhatnagar's solution to accept him as a research student in emulsification, a branch of colloidal chemistry. The Privy Council of Scientific and Industrial Research granted Bhatnagar an annual grant of £ 250 which enabled him to spend some time in France and Germany, interacting with prominent scientists. In April 1921, he successfully defended his thesis on *Inversion of Emulsions* and was awarded the D.Sc. He was soon flooded with offers from India.

On his return to India in 1921, he took up the physical chemistry chair at the newly established Banaras Hindu University (BHU). There, he worked for three years creating an active school of physico-chemical research, which soon had a reputation comparable to that of the Indian School of Chemistry under P. C. Ray. Bhatnagar also composed the *kulgeet* (university song) in Sanskrit which to this day is sung by the students of BHU on ceremonial occasions.

While he was attending the 1923 Liverpool session of the British Association for the Advancement of Science, Bhatnagar came across an advertisement in *Nature* for the post of Director of the University Chemical Laboratories in Lahore. When he applied for the post he found himself in direct contest with his former professor Willsden. However, Bhatnagar was appointed for the post.

In Lahore, he resumed his research on problems in colloidal and photochemistry. There was no dearth of research workers, as students flocked to his laboratory from all over India including some from BHU. Between 1929 and 1939, Bhatnagar and his students published about 20 papers in Indian, British and German journals. Besides, his team also produced solidified hessian sheets which were better than thatch as rain-proof roofing and less expensive than slates for village houses in the hills. With Ram Narayan Mathur he devised an interference balance to measure the very small changes in the magnetic susceptibilites of substances in chemical reaction. The balance was later licensed to Adam Hilger and Company in London for manufacture. Commissioned by Macmillan, Bhatnagar also published a textbook, *Physical Principles and Applications of Magneto-chemistry*, in 1935. The book was well reviewed in scientific journals abroad and was viewed by many in India as a token of recognition in the west of the authority of an Indian scientist.

One of Bhatnagar's major achievements is the work he did for a British oil company. While drilling for oil at Rawalpindi the drilling mud would set into a solid mass when it came into contact with saline water. It hardened further and rendered all drilling impossible. Bhatnagar solved the problem by the addition of an Indian gum that lowered the viscosity of the mud suspension and protected it from the coagulating action of the electrolytic salts. The company was so pleased with the result that they offered Bhatnagar Rs. 1,50,000 for his research work on any subject of petroleum interest. Bhatnagar asked the company to place the money with the University instead. With this amount he engaged six research scholars and started a Department of Petroleum Research under his direction. This

department carried out important investigations on deodorization of waxes, increasing the flame height of kerosene, lubrication, prevention of corrosion and utilization of waste products in the vegetable oil and mineral industries.

When Arcot Ramaswamy Mudaliar convinced Viceroy Linglithgow of the need for a Board of Scientific and Industrial Research to mobilize Indian talent to meet the requirements of the World War II, Linglithgow wanted Bhatnagar to be its Director. Linglithgow even wrote to Governor Craig to get on lien for two years the man he considered *the most admirably qualified to help us in an issue of real significance*. Soon the laboratories of the Board started functioning from the Government Test House in Cal;cutta. When threats of Japanese invasion became more intense these were shifted to the Delhi University and the name was changed to the Council of Scientific and Industrial Research. Very soon several products of great importance had been developed by Bhatnagar and his staff such as gas masks with indigenous components, lubricating oil for bronze bearings in locomotives, air-foam solution, glass substitutes and plastics from Indian wastes. Bhatnagar had managed to harness science to propel India on the path of industrialization.

When the country gained its independence, the CSIR governing body was reconstituted with the Prime Minister as its President. Nehru and Bhatnagar shared a great rapport that was sustained to the end of Bhatnagar's life. Not only did Nehru retain Bhatnagar for six years after retirement at CSIR, but created a separate Department of Scientific and Industrial Research of which Bhatnagar was made the Secretary. Bhatnagar envisaged the establishment of a chain of laboratories throughout the length and breadth of the country that would not only become centres of excellence but would also provide gainful employment to thousands of countrymen. As his vision unfolded, the CSIR network started expanding. Before his death, twelve of these laboratories were fully functioning.

Ever since the death of his wife in 1946, Bhatnagar had become a workaholic. Maulana Azad who had appointed him the first Chairman of the University Grants Commission feared a breakdown of Bhatnagar's health and insisted on his taking a fortnight's rest and recuperation in Switzerland. But once back in India, Bhatnagar returned to his old ways. On a visit to the Himalayan Institute of Mountaineering, B. C. Roy found Bhatnagar having difficulty in breathing and advised him to take care of his heart. Not heeding the advice, Bhatnagar carried on till he suffered a heart attack on the night before New Year's Day 1955 while preparing for the Science Congress at Baroda. Maulana Azad had this to say to Bhatnagar, *I have lost a friend*. India, however, lost one of the most able administrators of science that the country has ever seen.



SATYENDRANATH BOSE

1894-1974

When the post of a professor fell vacant in Dacca University, S. N. Bose who had not yet got his doctorate, approached Albert Einstein for a recommendation to make things easy for him. Einstein was surprised. He wrote to the authorities of Dacca University, *Can you find another scientist as proficient as Satyendranath? He is quite fit for the post.*Bose was appointed Professor and Head of the Department of Physics.

Satyendranath Bose was born on January 1, 1894, in Calcutta. He was the eldest of seven children and the only son among six daughters. His

father Surendranath Bose was a trained accountant who held a responsible post in the Executive Engineering Department of the East Indian Railways. Amodini Devi, his mother, suffered from poor health all through her life. Surendranath took special care to see that nothing came in the way of the boy's education.

Young Satyendranath attended a neighbourhood elementary school in Calcutta. In 1907, he joined the Hindu School. His eyesight was weak but his intelligence and memory were sharp. He was deeply interested in science right from school days. After passing high school in 1909, Satyendranath entered the Presidency College. He recalled the period of his stay in Presidency College as the Golden Age. It was here that the company of good friends and classmates and the guidance of illustrious teachers shaped his future. Some of the most renowned scientists, Meghnad Saha, Nikhilranjan Bose, J. C. Ghosh, J. N. Mukherjee and Girijapathi Bhattacharya, were his classmates. He had as his teachers eminent scientists like J.C. Bose, P. C. Ray and S. N. Maitra. Satyendranath not only shared the excitement of acquiring scientific knowledge in the midst of illustrious company but also imbibed patriotic fervour from the Swadeshi movement, which was at its height.

Bose took his B.Sc. examination in 1913 and the M.Sc. degree in 1915 from the Calcutta University, standing first in both. It was around this time that Sir Asutosh Mookerjee laid the foundation of the University College of Science for postgraduate studies and research. In 1915, some of those who had secured the master's degree approached Sir Asutosh Mookerjee and requested him to open postgraduate courses in modern physics and modern mathematics in Calcutta University and allow them to teach. Among them were Meghnad Saha, Jnanachandra Ghosh, and Satyendranath Bose. In 1916, the University started M.Sc. classes in modern mathematics and modern physics. M. N. Saha, J. C. Ghosh and S. N. Bose were all appointed lecturers.

Bose began to learn French and German in order to read the European scientific literature. But because of World War I, it was difficult to order books from abroad. Bose and Saha then approached P. J. Bruhl, an instructor in the Bengal Engineering College, who possessed advanced textbooks on physics. After reading up on the developments in new physics, they took over the task of teaching postgraduate students and even began to teach relativity to their students, not attempted till then. Within a few years the Calcutta University became recognized as the leading institution for higher learning in the sciences.

After five years at the Calcutta University, Bose moved to Dacca University in 1921. It was around this time that his friend D. M. Bose returned from Berlin and brought with him new publications on the quantum theory. He gave Planck's *Thermodynamik und Warmestrahlung* (Thermodynamics and Heat) to Bose to read. The book contained all the original papers of the great physicist. Bose started working on the equations and formulae himself. At one place, Bose found that Planck had assumed some hypothesis and calculated an equation approximately. Bose worked out a better way to calculate the equation. He sent his four-page research paper, *Planck's Law and Light Quantum Hypothesis*, to an Indian journal and to several journals abroad. But all of them rejected it. In desperation Bose sent the paper to Einstein in 1924. Einstein was so impressed with the daring concept that he himself translated it into German and sent it for publication to a German journal, *Zeitschrift fur Physik* which published the paper in its August 1924 issue. Einstein also explained at length the significance of the subject matter of the paper and added a comment: *An important forward step*.

Bose's original approach struck Einstein who later systematically adapted Bose's approach in his own work and the particular field of Bose's research came to be known as *Bose-Einstein Statistics*. Of late, it has come to be known merely as *Bose Statistics*. Elementary particles, such as photons that obey

Bose statistics, are called `Bosons' thus ensuring a permanent name for Bose in science.

Bose managed to get a two-year study leave and sailed for Europe from Bombay in September 1924. After a brief sojourn at Paris he reached Berlin where he eventually fulfilled his long-cherished desire of meeting Einstein, whom he considered his guru. On his return to Dacca, Bose was appointed Professor of Physics in 1927. Bose was greatly loved and admired as a teacher by his students, and his colleagues held him in high esteem. He was informal and kept his door always open to anyone who cared to drop in. His bedroom also served as his study.

Bose returned to Calcutta University in 1945 as Khaira Professor of Physics. During another visit to Europe in 1954, Bose had wanted to go to the United States to meet Einstein again. However, since he had happened to visit Russia earlier the Americans thought of him as a communist and did not give him a visa. Tragically, Einstein's death soon after, dashed Bose's hope of meeting his guru again.

In 1954 the Government of India conferred the honour of Padma Vibhushan on him and Bose retired from Calcutta University in 1956. The University honoured him by appointing him Emeritus Professor. Later he became the Vice-Chancellor of the Visvabharati University. In 1958, he was made a Fellow of the Royal Society, London.

Though Bose was primarily a scientist, he was equally interested in literature, art and music. He could read and enjoy poems in Sanskrit, Bengali, English, French and Italian. Bose had made a deep study of several works in Bengali and English literature and also translated some French short stories. Very few people know that Bose could play well on the bowstring musical instrument, *Esraj*. A gifted musician and critic of music, he also created a few new ragas.

At a time when the majority of the Indian elite craved proficiency in English, Bose understood the importance of the Indian languages. He believed that if science is to be understood by laymen, it should be taught in the regional languages. He founded a science association named *Bangiya Vijnana Parishad* in Bengal in 1948 and all its correspondence was carried out in Bengali. From its inception, the association has been bringing out a periodical entitled *Jnan o' Bijnan*.

Within a few days of completing 80 years, Bose suffered a severe heart attack and breathed his last on February 4, 1974.



HOMI JEHANGIR BHABHA

1909-1966

Homi Jehangir Bhabha will always be remembered as the architect of India's nuclear energy programme. One of India's most outstanding scientists and an imaginative administrator with a multi-faceted personality, Bhabha was an ardent nationalist.

Bhabha was born in Bombay on October 30, 1909. His father, Jehangir H. Bhabha, once a student of Oxford University and a reputed advocate, had served Tata Enterprises. Meherbai, Bhabha's mother, was the grand-daughter of Sir Dinshaw Petit, First Baronet, and widely respected in Bombay for his philanthropic endowments. His paternal grand-father was the Inspector-General of education in the State of Mysore.

Bhabha was educated at the Cathedral and John Cannon High School, Elphinstone College and the Royal Institute of Science, Bombay. His parents took a keen interest in nurturing Bhabha's love for science. He had access to his grandfather's large

library which contained many books on science. At the age of 15, he had already read Einstein's book on Relativity. Apart from science it was his father's and aunt's collections of music and his grandfather's fine collection of books on painting and art that imbued him with a love for nature and a deep interest in painting, music and literature. His pencil sketches and some of his paintings are preserved in British art galleries. Since his paternal aunt was married to Sir Dorab Tata, as a young boy Bhabha would often go across the road to the ancestral home of J.N.Tata, the founder of the house of Tatas. There he would hear discussions relating to projects for the industrial development of India, ranging from iron and steel to the manufacture of heavy chemicals. All this developed a strong nationalism in him and the resolve to dedicate himself to India's progress and development.

Bhabha loved physics and mathematics. But bowing to his father's and Sir Dorab Tata's wishes, who wanted him to become an engineer and join the Tata Iron and Steel Company at Jamshedpur, Bhabha left for Cambridge in 1927 to study engineering. He wanted to change to mathematics but his father promised finance for further studies in mathematics, only if he got a first in engineering. He passed the Mechanical Engineering Tripos in the first class in 1930 and then went on to study theoretical physics as a research scholar. During the two years of his work at the Cavendish Laboratory, Bhabha won several scholarships, travelled across Europe and worked with Pauli in Zurich, Enrico Fermi in Rome and Kramers in Utrecht. His first scientific paper in 1933, dealing with the part played by electron showers in the absorption of gamma radiation won for him the Isaac Newton Fellowship in 1934. Three years later, he was awarded a senior studentship and he continued to work at Cambridge until the Second World War began in 1939.

Bhabha came into close contact with famous scientists such as Rutherford, Dirac, Niels Bohr and Heitler and when the discovery of the positron in 1932 opened up a wide field for theoretical physicists, he threw himself into this field of high-energy physics. Most of the 50 scientific papers he published were concerned with high-energy physics. In 1937, along with Heitler, he presented the Cascade Theory of Electron Showers which is today known as the 'Bhabha-Heitler Cascade Theory'. The theory explains the process of electron showers in cosmic rays.

Bhabha returned to India in 1939 and accepted the post of Reader at the Indian Institute of Science in 1940. He was in charge of a special cosmic ray research unit set up for him with funding from the Sir Dorab Tata Trust. During the five years of his stay in Bangalore, Bhabha gradually began to be identified with India's great culture. He analyzed the socio-economic problems of the day and was convinced that science was the only means for his country's progress. Bhabha dreamt of the 'great adventure' of building a modern India.

In 1941, he was elected a member of the Royal Society and became a Professor in 1942. The University of Cambridge awarded him the Adams Prize. He also received an offer from the Oxford University which he declined, for his heart nursed the desire to build an excellent institution of research in his own homeland. In 1944, Bhabha wrote a letter to the Dorabji Tata Trust in which he said: *There is at the moment no big school of research in the fundamental problems of physics. It is absolutely in the interest of India to have a vigorous school of research in fundamental research. When nuclear energy has been successfully applied to power production in, say, a couple of decades from now, India will not have to look abroad for its experts, but will find them ready at hand*.

Bhabha's plan was the embryo which was born as a school of physics. The next year, in 1945, the Tata Institute of Fundamental Research (TIFR) was inaugurated in a house in Bombay, the foundation stone of the present building was laid in 1954 and the Institute started functioning in 1962. Today, TIFR is one of the finest research institutions in the world.

The great expansion in the Indian economy demanded a steady increase in the country's electricity generating capacity. Bhabha believed that the only way of overcoming power hunger was through the introduction of nuclear power in a phased manner. In 1948, the Atomic Energy Commission was formed and Bhabha was appointed its Chairman. The Commission’s responsibilities included: a survey of Indian soils for the materials required for nuclear research, construction of atomic reactors, the purification of atomic materials, conducting fundamental research, and development of training programmes.

The Commission utilized the services of scientists at TIFR. Soon the Commission's scope was enlarged and the Atomic Energy Programme began to take shape. The Department of Atomic Energy thus came into existence as a separate Department of the Government of India in 1954, under the direct control of Prime Minister Nehru. Bhabha became the ex-officio Secretary of the Department.

Shortly after the formation of the Department of Atomic Energy, it was decided to create the Atomic Energy Establishment at Trombay for the application of atomic energy to peaceful purposes. While the construction work at Trombay was still in progress, Bhabha spent many sleepless nights and finalized the layout for the campus. He became its first Director in 1957. At a ceremony attended by well-known international figures, on January 12, 1967, Prime Minister Indira Gandhi renamed the Trombay Establishment as Bhabha Atomic Research Centre.

Bhabha worked to make the country self-reliant in the nuclear field. He stressed that while India needed to draw on the expertise already built up in other countries, her objective must be to exploit her own resources of scientists and technologists as well as the raw materials. With the support and encouragement he got from J. R. D. Tata and Jawaharlal Nehru, Bhabha enjoyed considerable freedom to carry on his work with ease and efficiency. Reactors like Apsara, uranium and zirconium plants, the Van de Graff and cyclotron equipment—were all Bhabha’s gifts to the nation.

He was awarded honorary doctorates by several Indian and foreign universities including the University of Cambridge, Padua, Perth, Banaras, Agra, Patna, Lucknow, Allahabad, Andhra and Aligarh. In 1954, the President of India bestowed him the Padma Bhushan honour for his outstanding contributions to nuclear science. In 1955, Bhabha was elected President of the first International Conference on the 'Peaceful Uses of Atomic Energy', organized by the United Nations at Geneva. Bhabha was the first scientist to advocate the peaceful use of atomic energy at international forums.

The crowning success of Bhabha’s life-long passion came on May 18, 1974 when India conducted its first nuclear explosion for peaceful purposes at Pokhran in Rajasthan. India became the world's sixth nuclear power. However, Bhabha did not live to see his dream prosper further.The Air India Boeing 707 'Kanchenjunga' in which Bhabha was travelling to attend an international conference crashed in a snowstorm on Mont Blanc on January 24, 1966, bringing to a tragic end the life of one of the great scientists of India.



VIKRAM AMBALAL SARABHAI

1919-1971

Had he so wished, he could have become an industrialist. But Vikram Ambalal Sarabhai’s heart was in basic research in mathematics and physics and the interest of his motherland uppermost in his mind in whatever he did. He encouraged students to go abroad

for higher studies in the latest areas of S&T but insisted that they return to serve India. He was confident that if the right atmosphere was created for the young scientists to pursue their chosen line of research in India, they would gladly return.

The Sarabhais were a famous industrialist family in Ahmedabad. They were also dedicated social workers. When their first daughter, Mridulaben, was just three years old, father Ambalal and mother, Sarala Devi began to think about her education. The Montessori system of education was gaining fame during that time, but there was no school here yet in this system. So, the Sarabhais started a school in their own house with their own eight children. Vikram was born into the Sarabhai household on 12 August 1919. As the children grew, more teachers were employed. At one time, the school had thirteen teachers for the eight children, teachers to teach languages, the sciences, the arts, gardening, and technology. The school also had its own laboratories and workshops. Vikram showed great earnestness and interest in his studies and was specially enthusiastic about mathematics and science.

Vikram came under the influence of many great persons — Mahatma Gandhi, Rabindranath Tagore, J. Krishna Murthi, Motilal Nehru, V. S. Shrinivasa Shastri, Jawaharlal Nehru, Sarojini Naidu, Maulana Azad, C. F. Andrews, and C. V. Raman — who stayed with the Sarabhai family whenever they visited Ahmedabad. Vikram loved adventure. As a child he impressed people with the many tricks he could perform with his bicycle. As the bicycle shot forward, he would raise his hands, stretch his legs forward, close his eyes and pedal.

After completing his college education, Vikram went to Cambridge University and took his Tripos in Physical Sciences in 1939. Vikram's first love was cosmic rays. Cosmic rays are a stream of energy particles reaching the earth from outer space. On their way to the earth they are influenced by the sun, the atmosphere and the magnetism of the earth. His basic interest was to find out how the rays vary with time and the implications of this phenomenon.

After his return, he did research for a while at the central meteorological station in Poona, and in 1943, he went to the Himalayan peaks in Kashmir to study the intensity of cosmic rays. He was so thrilled that he decided to establish a high altitude research centre. In 1945, when World War II ended, Sarabhai once again went to Cambridge to continue the study of cosmic rays and received his Ph.D. in 1947.

Shortly after he returned from Cambridge, he established the Physical Research Laboratory (PRL) at Ahmedabad, an institution devoted to the study of cosmic rays and outer space. Starting with just a few students and laboratory assistants, the group soon developed into a dedicated team of scientists and research workers. Today, it is a premier institution that provides the technology and the scientists needed for the country's space research programme. In spite of his many duties in later years, Sarabhai maintained close contact with PRL all through his life. In 1955, Sarabhai set up a branch of the Physical Research Laboratory at Gulmarg in Kashmir. Impressed by the work done at this centre, the Atomic Energy Department of the Government of India established a full-fledged High Altitude Research Centre at the same place — the only research centre in the world at such an altitude.

Sarabhai will always be remembered as one who ushered in the space age in India by expanding the Indian Space Research Organization (ISRO) which he served as Chairman. He was also responsible for the establishment of the Space Science and Technology Centre at Thumba and the Experimental Satellite Communication Earth Station at Ahmedabad. He established the Rocket Launching Stations at Thumba and Sriharikota. To Sarabhai goes the credit for the many achievements of the Indian space programme during its early years, although he did not live to see the fruits of his labour. Among the projects he planned was the one under which India's first satellite, Aryabhata, was launched in 1975. The groundwork for the Satellite Instructional Television Experiment (SITE) in 1975-76 which sought to bring education to

five million people in 2,400 Indian villages, was also done by Sarabhai.

Although he had enormous wealth and rich industrial experience, Vikram Sarabhai was a very modest, soft-spoken and simple man. He looked on all persons as equal and judged each only by the measure of work and responsibility. Sarabhai working in his laboratory at midnight was a common sight and he hated to waste time. Even when waiting to board a plane, he would get together with students in some corner of the airport to discuss work. There was a big pharmaceutical factory of the Sarabhais in Baroda and every Friday he would go there to supervise the work and give instructions. On the train journey from Ahmedabad to Baroda, he would take one or two students to travel with him and discuss their research problems.

In 1947, at the age of 28, he was entrusted the organization of the Ahmedabad Textile Industry Research Association (ATIRA). He had then no experience of textile mills or textile technology. Yet, his intellect and confidence helped him build the institution. In 1956, when the Productivity Congress met in Japan he led the Indian delegation. He was only 37 then.

Sarabhai built a number of institutions during his lifetime-- and not all of them were scientific institutions. In 1963, he established the Nehru Foundation for Development, for the study of social and educational problems. In 1966, under its auspices, he established the Community Science Centre, whose object was to spread scientific knowledge, to create interest in science and to promote experimentation among students, teachers and the general public. Few may know that it was Sarabhai who established the Indian Institute of Management at Ahmedabad.

Vikram Sarabhai received several honours for his services to science and society. In 1966 he received the Padma Bhushan. Vikram Sarabhai breathed his last on 31 December 1971 at the young age of 52. After his death, the Government conferred on him the honour of Padma Vibhushan in 1972. The International Astronomical Union named a crater after him on the moon in the Sea of Serenity.

Sketchs of J.C. Bose, P.C. Ray, S. Ramanujan, C.V. Raman, S.S. Bhatnagar and H.J. Bhabha in this chapter have been prepared by V.N. O'Key, published in Architects of Modern India.

Humanity needs practical men, who get the most out of their work, and, without forgetting the general good, safeguard their own interests. But humanity also needs dreamers, for whom the disinterested development of an enterprise is so captivating that it becomes impossible for them to devote their care to their own materials profit.

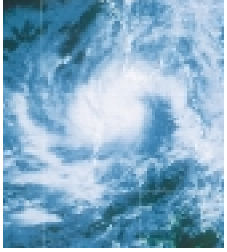
Without doubt, these dreamers do not deserve wealth, because they do not desire it. Even so, a well-organized society should assure to such workers the efficient means of accomplishing their task, in a life freed from material care and freely consecrated to research.

- Marie Curie



LAYING THE FOUNDATION OF RESURGENT INDIA

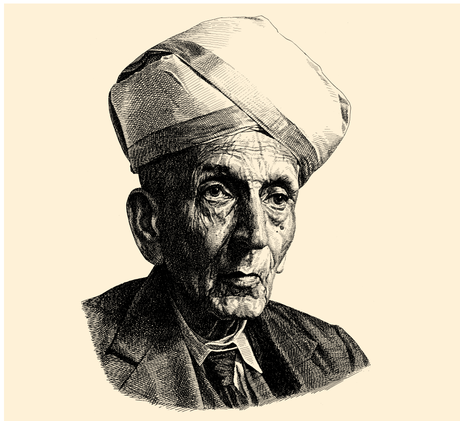
Taking the path of non-violence, Mahatma Gandhi led India to Independence. We were blessed with leaders who were determined to build a strong democratic nation free from poverty, hunger, ill-health, ignorance and fear. They recognized the value of education in general and of science and technology in particular to realize these goals. An overview of the endeavours in this direction is presented by a doyen of science. Developments in education in science, engineering and technology are traced by two eminent scientists. There is reason to feel jubilant that Indian students are winning medals in International Science Olympiads.



CHAPTER III

SCIENCE AND TECHNOLOGY SINCE INDEPENDENCE: AN OVERVIEW

In 1947, India was fortunate in having a strong foundation for science and technology (S&T) which could be regarded as among the foremost of all developing countries which had gained freedom around that time. Whilst some of this was due to traditions going back to the origins of Indian civilization, a large part of the modern base was due to the endeavours of individuals, like Mahendra Lal Sircar and Asutosh Mookerjee in Bengal and J. N. Tata in Mumbai, who were great promoters of science, and the outstanding work of many Indian scientists like J.C.Bose, P.C.Ray, Srinivasa Ramanujan, C.V.Raman, S.K.Mitra, Birbal Sahni, Meghnad Saha, P.C.Mahalanobis, S.N.Bose, Vikram Sarabhai and many more whose brief sketches have been featured as torch bearers in this volume. All these scientists worked in educational institutions, and their achievements were at par with the very best in the contemporary world -- C. V. Raman did win a Nobel Prize; some others could and should have won, considering their contributions. Their work was essentially 'small science' in today's context. There were also achievements by engineers, notably M.Visvesvaraya, which laid the foundation for self-reliance and self-confidence, in taking up large complex projects such as dams, irrigation systems, generation of electricity and the like. It is important to emphasize that these remarkable men were products of the indigenous culture, largely self-taught, and without the advantages of foreign education and guidance.

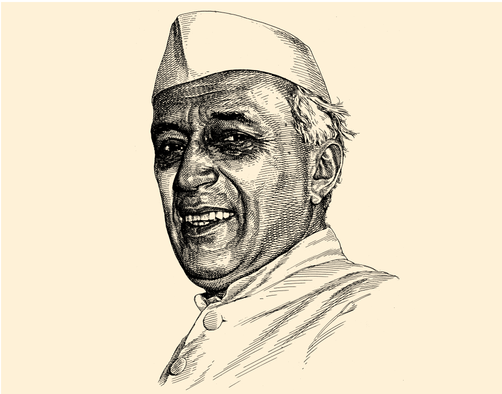


M.Visvesvaraya (1861-1962): A pioneer engineer-statesman.

At the time of Independence, however, despite the scintillating contributions that had been made to modern science, there was nothing in the economy to speak of. Growth rate in agriculture was only 0.3 per cent. The manufacturing industry was woefully small. The knowledge base was ready for a modern scientific and industrial infrastructure to be built, envisioning a future for the new nation.

THE NEHRU YEARS

In 1947, the year of Indian Independence, addressing the Indian Science Congress held in New Delhi as its President, Jawaharlal Nehru remarked: *We have to find food for them, clothing, housing, education, health and so on, all the absolute necessities of life that every human should possess. So science must think in terms of the few hundred million persons in India.*



Jawaharlal Nehru (1889-1964): Architect of modern India.

Nehru was clear in his mind about the relationship between science and society as a whole and its relevance, in the Indian context, for meeting the basic needs of large numbers. This was a recurring theme in his thought and deliberations. It was Nehru who envisioned the role of S&T to underpin and accelerate national development, science being an important element in modernizing the country to bring about what he repeatedly referred to as 'scientific temper' in society, an essential aspect of the culture of a new civilization.

Nehru promoted the growth of science in every conceivable way. He travelled the length and breadth of the country to open laboratories, to attend scientific meetings, and notably the Indian Science Congress at the beginning of each year. He supported the aspirations of major players -- Homi Bhabha, to develop the Indian atomic energy programme, which later nurtured the Indian space programme; S.S.Bhatnagar, to create the chain of laboratories of the CSIR; P.C.Mahalanobis, to generate the base of statistics in terms of research, training and application as an enabling tool, particularly for planning; and D.S. Kothari to initiate work in defence research which grew into the Defence Research Development Organization. The high point of what Jawaharlal Nehru did for science was embodied in the Scientific Policy Resolution, adopted by the Government of India on March 4, 1958 (see annexure I). It was a fairly unique statement then for any country, leave alone a developing country

During the years that Nehru was Prime Minister, there was massive quantitative expansion of the educational system at all levels -- from primary schools to universities. However, a significant major initiative was the setting up of some unique institutional systems, namely, the Indian Institutes of Technology (IITs), Indian Institute of Management (IIM) and All India Institute of Medical Sciences (AIIMS) which are academic, degree-granting institutions, but set apart from the normal university system. The IITs, primarily based on the Sarkar Committee Report, were designed to be the leaders in the field of technical education. Nehru remarked: *While it is relatively easy to put up a factory or a plant or a project, it is much more difficult and it takes much more time to train the human being that will run a factory or plant*. Overall, the graduates of the IITs have been remarkably successful. The selection procedure, involving a stiff entrance examination, ensured outstanding input and the undergraduate B.Tech. programme has maintained very high standards. Today, many of the graduates from the IIT system occupy some of the most distinguished positions in business, industry and government in the country and abroad. The IIT B.Tech. has become one of the prized brand names to emerge from India. The same applies to the IIMs and AIIMS.

The Nehru period was thus characterized by massive development of an infrastructure for S&T, and for the promotion of quality and excellence. The next twenty-five years in the nation's life brought maturity in facing challenges even while reaping the successes that followed.

Confidence and Striving

In January, 1966, Indira Gandhi became Prime Minister of India. Her approach to science was very similar to that of her father, Jawaharlal Nehru. She remarked: *Science, with its spectacular achievements, in increasing production and multiplying a thousand-fold the speed of man's movement and the range of his sight and sound, has aroused limitless expectations.*

What is more, it has the capacity to fulfill them. The challenge before leaders of science and the moulders of national and international policies is how to direct the removal of hunger, want and the diseases of privation.

The emphasis on the role that science can play in bringing about a better quality of life for humankind is obvious. But again, like her father, Indira Gandhi had a holistic view, with a deep appreciation of the interplay of the many elements that make up life: the environment from which we derive sustenance, human culture and creativity, and the development and use of capabilities to advance the well-being of society. In her own words: *Planned support for science has been one of the major commitments of governmental policy in Independent India. Jawaharlal Nehru recognized that the change of material conditions and means of production could be brought about only through a programme of scientific research and development. Science, to him, was the Bow of Shiva with which to vanquish poverty*.

The Green Revolution: One of the important areas of success in Indira Gandhi's early tenure as Prime Minister was achieved in the effort to significantly increase food production. It came about through a combination of clear-cut political decisions, good administrative support, and high quality applied research. It made the fullest use of new developments in agricultural research from abroad, which were then adapted to local conditions and blended with existing resources and cultural practices. There was good team work in extension, education and dissemination. This brought about the 'Green Revolution'. From a figure of around 50 million tonnes in the 1950s, grain production has quadrupled to around 200 million tonnes now. Not only in the case of grain, but over a wide range of agricultural products, there has been enhanced production, productivity and diversification.

The Green Revolution and related developments in agriculture, along with the potential of the new developments in biotechnology, give confidence that India can be essentially self-



Jamsetji Nussarwantji Tata (1839-1904): He nurtured science and technology in India.

sufficient in the matter of food. A number of successful missions, among them the 'White Revolution' relating to the dairy industry and milk distribution, the construction of the largest irrigation network in the world, the growth of a chemical industry, which is one of the largest in the world, achieving contemporary international levels in process systems design and catalysis, all serve to illustrate what has been accomplished in largely diverse areas, all closely related to development.

During the 1970s and '80s a wide range of new enterprises were begun in areas of great importance to the nation's future, such as electronics, environment, new and renewable energy sources, ocean development and biotechnology. These have become major spheres of activity in their own right, and will bear fruit as we have moved into the new millennium.

Strategic Areas of Self-Reliance

India's nuclear programme was envisioned by Homi Bhabha for peaceful purposes, especially large-scale production of electricity. This is unlike the major players in this field (USA, USSR, UK, France and China) who had embarked initially on nuclear weapons programmes; for them nuclear power came later. In India, nuclear electricity came first, followed much later by nuclear tests at Pokhran in 1974 and 1998. In some other countries too, for example, Japan, nuclear electricity was the prime motivation. But India's efforts preceded all of these. The entire range

of technologies from prospecting for raw materials to the design, construction and operation of large power reactors is now available on a self-reliant basis.

The space programme, started by Vikram Sarabhai, was again for wholly peaceful developmental purposes like telecommunications, broadcasting, and remote sensing. Over a period of 40 years, capabilities have been developed to build operational satellite systems for all the above application areas. The launch of orbiting operational remote sensing satellites is now carried out on a routine basis. Launchers for orbiting operational geostationary satellites have also been tested. India's satellites, whether low orbiting ones for remote sensing or geostationary ones for telecommunications, broadcasting and meteorology, have performed at contemporary international levels. These are designed and built in India.

Defence research, whilst initially dealing largely with improvements to imported equipment and minor adaptations and modifications, rapidly moved forward to import-substitution. Over the last quarter of the century, it has taken on wholly a new range of manufacturing such as battle tanks, advanced guns, electronic warfare and guided missile systems, radar and communication systems, combat aircraft and the like. There is significant self-reliant, indigenous input in all of these and strong linkages are continually being established with the national research systems, as well as the industrial production systems.

Department of Science & Technology (DST): To provide a nodal point for science and technology in the broadest sense, apart from specific areas such as atomic energy, space, and electronics, Indira Gandhi set up the DST. It was this Department which created the first effective institutional framework for advice to Government on matters relating to science and technology by setting up the National Committee on Science and Technology in 1971. Many initiatives were taken by this body and its successors, the Science Advisory Committee to the Cabinet, which functioned from 1981 to 1986, followed by the Science Advisory Council to the Prime Minister, 1986 to 1990. It was the DST which provided the base for nucleating activities in the areas of ocean science and technology, new and renewable sources of energy, large-scale remote sensing, and of biotechnology. It has also provided broad-based support for research in a variety of disciplines in S&T.

Environment and Ecology: Environment and ecology gained international importance with the UN Conference on Human Environment held in Stockholm in 1972. From the local issues of air, water, and industrial pollution, going on to regional and trans-boundary impacts, and to environment in relation to health, discussions have now progressed to global issues such as ozone depletion and increase of carbon dioxide concentration in the atmosphere, and the consequent implications for climate change. The great importance of the earth's biodiversity, something that has come down through a large and complex process of evolution, as a rich resource for the future is an issue that has also come to the forefront. India has a good scientific base (including one in the use of powerful techniques of modern biology) to deal with this area.

Indira Gandhi was always deeply interested in the cause of the environment. She was one of the two Heads of Government who attended the 1972 UN Conference in Stockholm. It was there that she made her famous statement: *Are not poverty and need the greatest polluters? The environment cannot be improved in conditions of poverty. Nor can poverty be eradicated without the use of science and technology.* She was the first world leader to explicitly relate environment to poverty eradication. In 1972, she established the National Committee on Environment Planning and Co-ordination, which set the tone and ambience for such work in India. In 1981, the Department (now Ministry) of Environment and Forests, came into being.



Indira Gandhi (1917-1984).

Renewable Energies: Indira Gandhi set up a Commission on Additional Sources of Energy that became the base for establishing the Department (and now Ministry) of New Energy Sources. It is clear that this is a pursuit of utmost importance for India, as we search for all possible ways to meet our energy needs, particularly in the vast rural hinterland where electrical transmission and distribution systems are rudimentary or absent. To set up the conventional systems in these regions would call for very large investments and long time scales besides other costs. Renewable energy systems would ensure sustainable development, while reducing usage of fossil fuels at the same time. This is clearly an area for thrust and emphasis, in this century.

Electronics and Information Technology: After the hostilities with China in late 1962, Homi Bhabha pointed out to the Government of India that research as well as production in various sectors of electronics, particularly in strategic areas, was not in a satisfactory state. Thereafter, a Committee was set up under his chairmanship, whose report he finalized but it was actually presented to Prime Minister Indira Gandhi a few weeks after he died in a tragic air crash in 1966. Initially, the Government tried to implement the recommendations of this Report through another committee. Five years later, when Indira Gandhi discovered that this had not worked, she set up a separate Department of Electronics and an Electronics Commission.

Whilst the Department of Electronics had to deal with the usual areas of industrial licensing, clearance of imports and the like, as called for by the country's laws, its principal focus was on promoting areas of high technology in terms of research and production. Two major programmes were implemented for the defence services. One was the Adges Plan for the Air Force, in which it was necessary to integrate and operationalize radar systems set up to monitor incoming threats, with communication systems which transmit this information to ground bases, along with computer hardware and software capable of analysing the threat and setting in motion necessary counter measures. This was done successfully on an indigenous basis.

The other programme was the Aren Plan which was a complete communication network for the Indian Army, from field levels to headquarters. Through these plans, very significant capabilities were built up relating to static and mobile radar systems, mobile and wireless communication networks and associated computer systems. This was the first major effort in which electronic switching was introduced in a networking mode linking wired and wireless systems. The automatic electronic switch developed for Plan Aren along with the work at the Telecommunication Research Centre of the Ministry of Communications on digital electronic switching, became the base, in the '80s, for setting up the Centre for Development of Telematics. This Centre was responsible for the development and induction of indigenous electronic switching on a very large-scale into the national communication system, particularly for the rural areas.

An area to which the Electronics Commission devoted considerable attention was that of computers. Major computer systems were inducted into the country for use as stand-alone systems at regional and national centres. Two major national centres were set up: one was a National Centre for Software Development and Computing Techniques (which has since become the advanced National Centre for Software Technology); and the other was

the National Informatics Centre which brought in large-scale database management into Government systems and established a network for information gathering, storage, accessing and communication, across the country at all levels, from the village *Panchayat*, to District, State and up to the Centre.

When restrictions were imposed by the United States on import of supercomputers by India, even though these were meant for meteorological long range weather forecasting and for scientific research of a broad nature, India mounted an effort to develop supercomputers working on parallel processing. Whilst work on this project was carried on independently in the atomic energy, defence and industrial research systems, the main national effort was concentrated at the Centre for Development of Automatic Computing which successfully developed parallel computing which could effectively do what the systems earlier planned for import were meant for.

In order to be part of the global electronic system relating to exports/imports, export processing zones were set up; the first was at Santa Cruz in Mumbai in the early '70s and Software Technology Parks established in the '90s; the latter was the basis on which Indian software companies were able to establish themselves in the country to embark upon major software export tasks.

An important initiative taken up by the Electronics Commission in the early '70s was to establish facilities for the production of semi-conductor devices with a resolution of a few microns, which would have been contemporary then. However, unfortunately, for a variety of reasons, largely related to administrative decision making in Government, this programme did not progress.

Whilst software development and exports started to grow on a significant basis towards the latter part of the 1990s, particularly with the IT boom that was taking place globally, the Government took a decision in 1998 to set up a National Task Force on Information Technology and Software Development. This body has submitted several reports to the Government during the short period that it functioned. These deal with the large-scale growth of information technology in the country including generation of human resources, e-governance, software development and exports, development of a content industry, promotion of hardware manufacture in the country and many such related issues.

Micro-electronics enabled the computer revolution: we are now into the age of informatics -- with computers and communications merging into a single stream, bringing together all types of media relating to information storage, access, dissemination, computation and analysis. Information Technology (IT) represents a revolutionary tool, which promises to transform every facet of human life and usher in a knowledge-based society in the next century; it will bring about connectivity of each human being on earth to all others. There has been increasing recognition in India of the importance of IT in national development. In a variety of ways, India now has a base to embark on an IT programme that will enable it to emerge as a major global player. The new National Informatics Policy can bring this about. The wide ranging and rapidly growing capabilities in IT are the result of efforts in strategic areas such as defence, nuclear and space research, as well as other government initiatives relating to software development and database management, parallel computing, digital communication systems, and the rapid growth of the private sector in the field of software, particularly for exports.

Institutional Framework for Advice to the Government at High Level on Matters Relating to Science and Technology

There has always been an apex level structure for advising the Government on policy issues relating to all aspects of S&T. Some of these structures in the past were: (a) Advisory Committee for Co-ordinating Scientific Work - 1948; (b) Scientific Advisory Committee (SAC) - 1956; (c) Committee on Science & Technology (COST) - 1968; (d) National Committee on Science & Technology (NCST) - 1971; (e) Science

Advisory Committee to the Cabinet (SACC) - 1981-1986, and (f) Science Advisory Committee to the Prime Minister 1986-1990.

In addition, a Cabinet Committee on Science and Technology was set up in 1981, under the chairmanship of the then Prime Minister, to oversee and provide policy guidance for the development of the S&T sector. In 1986, a Scientific Adviser to the PM was appointed in addition to a Science Advisory Council to the Prime Minister (SAC-PM), largely consisting of scientists and technologists from outside the Government system.

NCST (1971-1980): The National Committee on Science & Technology (NCST), particularly when it was first constituted in 1971, performed an important role in trying to link science and technology development to the planning process for which it produced an S&T plan. It also devised means to promote science and technology promoted by the State Governments through appropriately constituted bodies.

SACC (1981-1986): Important developments that arose out of deliberations of the Scientific Advisory Committee to the Cabinet (SACC) during its tenure from 1981-1986 were:

- Setting up of a National Science and Technology Entrepreneurship Development Board (NSTEBD) so that scientific capabilities, financial resources, as well as local natural resources and needs, could all be integrated with significant employment potential.
- Recognition of the spectacular advances taking place in the life sciences and in their application through biotechnology which, in time, would be of great importance in areas of food and health, apart from their deep significance for many other aspects of human life. To take care of this area, a National Biotechnology Board was initially set up, which has now evolved into the highly active and promotional Department of Biotechnology.
- The National Council for S&T Communication (NCSTC) was set up in 1982, and it continues to function and organize a variety of activities that relate to science communication and aspects relating to promotion of scientific temper in the society.
- A scheme referred to as COSIST was established to ensure further support through the University Grants Commission for groups and departments in educational institutions that had established their credibility for high quality teaching and research in S&T.
- By analogy with the Indian Council of Agricultural Research (ICAR), a new set-up was created for the sector of forestry, in the Indian Council of Forestry Research & Education (ICFRE).
- Considerable efforts were put in to strengthen the areas of S&T in forensic activities under the Ministry of Home Affairs.

SAC-PM (1986-1990): In 1986, Prime Minister, Rajiv Gandhi decided to replace SACC by a smaller committee consisting of only non-official working scientists to advise him on major issues of S&T, its health and the direction in which it should move. This committee was designated Science Advisory Council to the Prime Minister (SAC-PM). It was expected to examine certain matters concerned with the scientific departments, priorities in research and development and monitor the technology missions initiated in 1985. In addition, it was to prepare a perspective plan for AD 2001. The Council got in-depth studies carried out by experts drawn from all parts of the country on major issues of societal concern, e.g. food security, watershed management, population control and improvement of human health, protection of environment etc. At the same time it commissioned studies on frontier areas of S&T like advanced materials, photonics, parallel computing, lasers, robotics and manufacturing automation.

The Council presented its recommendations to the Prime Minister at regular intervals.

An empowered committee headed by the Cabinet Secretary was charged with the responsibility

of implementing any programmes emanating from these deliberations. This often required coordination of activities of several departments and agencies of the Government. The Council reviewed some of the recommendations of the SACC and in consulation with the Scientific Adviser to the Prime Minister ensured their implementation. Some of the major outcomes of Council's efforts were the creation of C-DAC which developed supercomputers strengthening of activities in the field of telecommunications, laser and robotics and superconductivity research. The Council also made recommendations on the use of S&T in planning, its integration with economic planning and planning for S&T *per se*. Those interested may consult the Council's publication, *Perspective in Science & Technology*, published in two volumes by the DST in 1990.

A Scientific Advisory Committee to the Cabinet (SACC) was constituted in June, 1997. This was an Advisory Committee to the Cabinet and the terms of reference were: rendering advice on the implementation of S&T policy of the Government; identifying and recommending measures to enhance the country's technological self-reliance and also foreign collaboration; and considering policy issues for the development and application of science and technology and organizational aspects of S&T institutions. The Committee also looked into the issues relating to filling critical gaps in national competitiveness, promoting technological co-operation amongst developing countries, emerging changes from international competitiveness in S&T and other international matters.

The tenure of the Committee was for two years. The SACC had considered various issues relating to autonomy of scientific institutions, guidelines for technology transfer, modernization of patent office, revision of fellowships for research students, special incentives for women scientists and strengthening of infrastructure and improvement in the universities and related S&T institutions.

The SAC (C) was reconstituted in March, 2000. The terms of reference were almost same as the earlier SACC. This Committee has also held two meetings to discuss simplification of administrative and financial procedures, human resource development, especially women scientists, core competence of the nation, among other matters.

There is also a Consultative Group of Government departments and agencies on S&T. The terms of reference are to evolve mission and action plans for implementation of S&T policy, to review the scientific and technological progress of missions, to suggest schemes to nurture a scientific environment and other important matters for development and application of S&T in different sectors. An Expert Committee of Senior Scientists has also been set up.

The Technology Policy Statement

Perhaps, the most important conceptual initiative of SACC was in the drafting of the Technology Policy Statement (TPS, see annexure II) adopted by the Government in 1983; this was announced by the Prime Minister, Indira Gandhi, in her inaugural address at the annual session of the Indian Science Congress in Tirupati in January 1983.

The fundamental approach of the Technology Policy Statement was to ensure that S&T is applied in a manner relevant to country's development. It focused on aspects of efficiency, employment, environment and energy. The essence of the Technology Policy is: *In a country of India's size and endowments, self-reliance is inescapable and must be at the very heart of technological development. We must aim at major technological breakthroughs in the shortest possible time for the development of indigenous technology appropriate to national priorities and resources.*

A Technology Policy Implementation Committee (TPIC) examined the TPS in detail to spell out measures needed for its implementation. Two of the measures worked out by TPIC have since been implemented. One is the setting up of a Technology Information Forecasting and Assessment Council (TIFAC) to ensure the availability of full information on the technology

scenario in the world and within India as also to ascertain developments that are likely to occur and the capability to assess and choose the technologies most relevant for the nation's needs. Another recommendation was the setting up of the Technology Development Fund, which would support all proposals considered *prima facie* suitable for the development of advanced and relevant technologies. Today these are being implemented by bodies under the purview of the DST.

Science, Technology and Planning

The Planning Commission of India has had an important role to play in matching various national objectives with S&T programmes, reconciling: differing priorities and viewpoints; resource availability and investment priorities; allocation of responsibility between the Centre and the States, and between public and private sectors; and bringing about integration between various sectors of the economy. As a result of concerted efforts of the Planning Commission and the DST (particularly through the initiatives of NCST and SACC), the States and Union Territories have also set up their own S&T Councils and/or Departments of Science and Technology. For identification and formulation of the S&T component in the socio-economic sectors, the larger Ministries and Departments have created their respective Research Advisory Committees (RAC) and Science & Technology Advisory Committees (STACs) with the DST organizing interdepartmental coordinating meetings for STACs.

The VI, VII and VIII Five Year Plans did have a strong focus on development of capabilities in S&T and on areas of strategic applications, but they also made the effort to relate these to the priorities of national development, particularly for the upliftment of the rural people, weaker sections and ecospecific regional issues. Accordingly, the Planning Commission conducted detailed studies of the Island territories of Andaman and Nicobar and Lakshadweep and prepared plans for ecospecific development in these parts with S&T based approach to energy, employment, fishing, water harvesting and the like.

Another important aspect of the interaction between the Indian planning process and the scientific development sector has been their remarkable mutual responsiveness. While the Planning Commission related to national needs at a given time, the scientific sector focused its R&D efforts to match it.

An analysis of the principal objectives of each of the Five Year Plans and corresponding scientific efforts illustrates the above. The II Plan dealt with the setting up of heavy industries and raising the low savings rate; this was conceived principally by Mahalanobis. The III Plan focused on import substitution because of the problem of balance of payments faced by the country, with falling international prices of primary products. The IV Plan followed a period of devastating droughts with consequent food shortages, food imports and devaluation; this clearly called for efforts to ensure food security. The V Plan recognized that reduction of poverty by the trickle-down process through industrialization had not worked, and there was need for positive anti-poverty programmes and a strong effort to meet the minimum needs of vast numbers. The VII Plan recognized the excess capacities in heavy industry generated through the success of the II Plan, and the need to deal with infrastructure. The VIII Plan was directed towards the creation of infrastructure, relating particularly to sectors such as energy, support of sunrise industries and the like. The VIII Plan took place with the opening up of the economy to the global winds of change, bringing about a market orientation through liberalization and economic reforms. The IX Plan has laid emphasis again on agriculture.

When one looks at each of these thrust areas of a given Plan period, determined by national needs at that time, one also discerns a trend in the scientific effort of that period and support provided, particularly where applications are concerned. There was a focusing of scientific effort to ensure that the basic objectives of that Plan period were met. In addition, long horizon programmes in the strategic sectors of atomic energy, space and defence research were supported in fulfillment of their original objectives.

The Mission Approach

Several new mechanisms were evolved by the Planning Commission, particularly in the VII Five-Year Plan period, to ensure that S&T capabilities are brought to bear appropriately on problems clearly defined on the basis of national objectives and needs. In particular, the following four are important: (a) the mission approach, (b) integration of S&T in the socio-economic sectors, (c) application of S&T for rural development and poverty alleviation, (d) S&T for societal development (to benefit specific beneficiary segments).

The mission approach was conceived, for the first time, and initiated during the VII Five-Year Plan period. The approach was to first define the total task to be accomplished and identify all the components needed for this purpose, including the S&T component. The latter would be undertaken by scientists who would then expect to see the fruition of their work in achieving the end results through the effective establishment of live and organic linkages between various organizational structures. These linkages would include administrative ministries, financial aspects, and the coordination between various scientific components along with the institutions concerned with them, and the actual field work. A mission oriented ethos, it was felt, would introduce a sense of urgency with clear-cut time and cost schedules, monitoring mechanisms and a new management approach. This is what was done in the case of the atomic energy and space programmes, and was being implemented for defence projects.

Six National Technology Missions, in areas of direct relevance to society and envisaging entirely new management approaches, were launched. These covered: increase of oilseed production; mass immunization; better communications; improving clean drinking water supply; raising milk production; and reduction of illiteracy. Similarly, nine S&T projects in the Mission Mode were taken up during the same Plan, with emphasis on an end-to-end approach with a significant research and development component, but connected with the financial, administrative and management aspects. These included missions such as cattle-herd improvement, bio-environmental control of vector borne diseases and so on.

The Future

The development of S&T in India since Independence has been essentially based on visionary support by political leadership at the highest level, namely, Jawaharlal Nehru and Indira Gandhi; and, to some extent, Rajiv Gandhi, who unfortunately did not live to have the necessary time span. The other driving force behind the development of technology in India has been the presence of visionaries of science, such as Homi Bhabha for the atomic energy programme, Vikram Sarabhai for the space programme, S.S. Bhatnagar for CSIR and B.P. Pal for agricultural research. There were also others, such as D.S. Kothari in the field of higher education and defence research, and P.C. Mahalanobis in the area of statistics. Many of these visionaries not only conceived of programmes with long time horizons, but generated leadership, often of their own calibre, to continue these.

From what was only small science of very high quality, the newly emerging nation, devoid of modern technology on any relevant scale, has moved significantly forward over the past five decades. There is now an industrial base to be reckoned with. In S&T, there is a major infrastructure and extensive coverage of a wider spectrum of disciplines than most countries in the world. Not only is it a matter of infrastructure and capabilities but also accomplishment of a high order.

There has, however, been a major change both, on the international scene as well as in India, over the past decade, as a result of advances in S&T, particularly in respect of IT and in transportation of goods and people. We now live in a highly interconnected interdependent world. This has led to globalization of markets which tend to look for resources, including financial, from all over the world, and bring these together at points where

production is most cost effective and efficient, and then move the goods to markets everywhere. This calls for a seamless or borderless world for movement of goods and of people. In recent years, India has embarked on a significant process of reform to move towards this globalization. It has to be remembered that India is endowed with highly competent trained human resources in a variety of fields and the cost of living in India is relatively low. Using current and developing information technology, it should be possible to shift a great deal of work to India from elsewhere in the world: in research, design systems engineering, software product development and applications.

While India has considerable industrial activity, it is still an agricultural country in terms of deployment of its population. The shift towards a greater role for industrialization, and from rural to urban centres is taking place in parallel with the IT revolution. There will also be a rapid move to a knowledge-based society. Hitherto, there has been some lack of coherence and interaction between India's scientific research and capabilities and its sectors of production and services. The situation is changing rapidly. The World Trade Organization and the new patent regime have created an awareness of the importance of Intellectual Property Rights and their role in the new world order.

There is enormous latent innovative capability in the Indian scientific system which could easily fructify into competence of value. This calls for support from other areas such as patent attorneys, patent offices and the financial sector. With the emphasis on experts and global competitiveness, the production sectors in India will increasingly turn to the scientific competence in the country, which is also liked with the global scientific enterprise.

As India develops and increasing numbers become well-to-do, they will move into the market economy on a scale that will fuel further growth. India represents a giant system, functioning as a democracy, moving from a conservative hierarchical society to a flexible, modern knowledge-based one. The foundations laid in creating its present wide-based competence in science and technology will stand it in good stead in this transformation.

Scientific Policy Resolution
Annexure – I

New Delhi, the 4th March 1958/13th Phalguna, 1879

- No.131/CF/57- The key to national prosperity, apart from the spirit of the people, lies, in the modern age, in the effective combination of three factors, technology, raw materials and capital, of which the first is perhaps the most important, since the creation and adoption of new scientific techniques can, in fact, make up for a deficiency in natural resources, and reduce the demands on capital. But technology can only grow out of the study of science and its application.
- The dominating feature of the contemporary world is the intense cultivation of science on a large scale, and its application to meet a country's requirements. It is this, which, for the first time in man's history, has given to the common in countries advanced in science, a standard of living and social and cultural amenities, which were once confined to a very small privileged minority of the population. Science has led to the growth and diffusion of culture to an extent never possible before. It has not only radically altered man's material environment, but, what is of still deeper significance, it has provided new tools of thought and has extended man's mental horizon. It has thus influenced even the basic values of life, and given to civilization a new vitality and a new dynamism.
- It is only through the scientific approach and method and the use of scientific knowledge that reasonable material and cultural amenities and services can be provided for every member of the community, and it is out of a recognition of this possibility that the idea of a welfare state has grown. It is characteristic of the present world that the progress towards the practical realization of a welfare state differs widely from

country to country in direct relation to the extent of industrialization and the effort and resources applied in the pursuit of science.

- The wealth and prosperity of a nation depend on the effective utilization of its human and material resources through industrialization. The use of human material for industrialization demands its education in science and training in technical skills. Industry opens up possibilities of greater fulfillment for the individual. India's enormous resources of manpower can only become an asset in the modern world when trained and educated.
- Science and technology can make up for deficiencies in raw materials by providing substitutes, or, indeed, by providing skills which can be exported in return for raw materials. In industrializing a country, a heavy price has to be paid in importing S&T in the form of plant and machinery, highly paid personnel and technical consultants. An early and large scale development of S&T in the country could therefore greatly reduce the drain on capital during the early and critical stages of industrialization.
- Science has developed at an ever-increasing pace since the beginning of the country, so that the gap between the advanced and backward countries has widened more and more. It is only by adopting the most vigorous measures and by putting forward our utmost effort into the development of science that we can bridge the gap. It is an inherent obligation of a great country like India, with its traditions of scholarship and original thinking and its great cultural heritage, to participate fully in the march of science, which is probably mankind's greatest enterprise today.
- The Government of India have accordingly decided that the aims of their scientific policy will be:

* to foster, promote, and sustain, by all appropriate means, the cultivation of science and scientific research in all its aspects -- pure, applied and educational;
* to ensure an adequate supply, within the country, of research scientists of the highest quality, and to recognize their work as an important component of the strength of the nation;
* to encourage, and initiate, with all possible speed, programmes for the training of scientific and technical personnel, on a scale adequate to fulfil the country's needs in science and education, agriculture and industry, and defence;
* to ensure that the creative talent of men and women is encouraged and finds full scope in scientific activity;
* to encourage individual initiative for the acquisition and dissemination of knowledge, and for the discovery of new knowledge, in an atmosphere of academic freedom;
* and, in general, to secure for the people of the country all the benefits that can accrue from the acquisition and application of scientific knowledge.

The Government of India have decided to pursue and accomplish these aims by offering good conditions of service to scientists and according them an honoured position, by associating scientists with the formulation of policies, and by taking such other measures as may be deemed necessary from time to time.

Extract from Technology Policy Statement Annexure – II

Preamble: Political freedom must lead to economic independence and the alleviation of the burden of poverty. We have regarded S&T as the basis of economic progress. As a result of three decades of planning, and the Scientific Policy Resolution of 1958, we now have a strong agricultural and industrial base and a scientific manpower impressive in quality, numbers and range of skills. Given clear-cut objectives and the necessary support, our science has shown its capacity to solve problems.

The frontiers of knowledge are being extended at incredible speed, opening up wholly new areas

and introducing new concepts. Technological advances are influencing lifestyles as well as societal expectations.

The use and development of technology must relate to the people's aspirations. Our own immediate needs in India are the attainment of technological self-reliance, a swift and tangible improvement in the conditions of the weakest sections of the population and the speedy development of backward regions. India is known for its diversity. Technology must suit local needs and to make an impact on the lives of ordinary citizens, must give constant thought to even small improvements which could make better and more cost-effective use of existing materials and methods of work. Our development must be based on our own culture and personality. Our future depends on our ability to resist the imposition of technology which is obsolete or unrelated to our specific requirements and of policies which tie us to systems which serve the purpose of others rather than our own, and on our success in dealing with vested interests in our organization: governmental, economic, social and even intellectual, which bind us to outmoded systems and institutions.

Technology must be viewed in the broadest sense, covering the agricultural and the services sectors along with the obvious manufacturing sector. The latter stretches over a wide spectrum ranging from village, small-scale and cottage industries (often based on traditional skills) to medium, heavy and sophisticated industries. Our philosophy of a mixed economy involves the operation of the private, public and joint sectors, including those with foreign equity participation.

Our directives must clearly define systems for the choice of technology, taking into account economic, social and cultural factors along with technical considerations; indigenous development and support to technical, and utilization of such technology; acquisition of technology through import and its subsequent absorption, adaptation and upgradation; ensuring competitiveness at international levels in all necessary areas; and establishing links between the various elements concerned with generation of technology, its transformation into economically utilizable form, the sector responsible for production (which is the user of such technology), financial institutions concerned with the resources needed for these activities, and the promotional and regulating arms of the Government.

This Technology Policy Statement is in response to the need for guidelines to cover this wide-ranging and complex set of inter-related areas. Keeping in mind the capital-scarce character of a developing economy it aims at ensuring that our available natural endowments, especially human resources, are optimally utilized for a continuing increase in the well-being of all sections of our people.

We seek technological advancement not for prestige or aggrandizement but to solve our multifarious problems and to be able to safeguard our Independence and our unity. Our modernization, far from diminishing the enormous diversity of our regional traditions should help to enrich them and to make the ancient wisdom of our nation more meaningful to our people.

Our task is gigantic and calls for close coordination between the different departments of the Central and State Governments and also of those concerned, at all levels, with any sector of economic, scientific or technological activity, and, not least, the understanding and involvement of the entire Indian people. We look particularly to young people to bring a scientific attitude of mind to bear on all our problems.

Aims And Objectives

Aims: The basic objectives of the Technology Policy will be the development of indigenous technology and efficient absorption and adaptation of imported technology appropriate to national priorities and resources. Its aims are to:

- attain technological competence and self-reliance, to reduce vulnerability, particularly in strategic and critical areas, making the maximum use of indigenous resources;
- provide the maximum gainful and satisfying

employment to all strata of society, with emphasis on the employment of women and weaker sections of society;

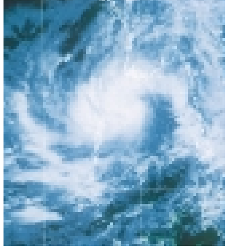
- use traditional skills and capabilities, making them commercially competitive;
- ensure the correct mix between mass production technologies and production by masses;
- ensure maximum development with minimum capital outlay;
- identify obsolescence of technology in use and arrange for modernization of both equipment and technology;
- develop technologies which are internationally competitive, particularly those with export potential;
- improve production speedily through greater efficiency and fuller utilization of existing capabilities, and enhance the quality and reliability of performance and output;
- reduce demands on energy, particularly energy from non-renewable sources;
- ensure harmony with the environment , preserve the ecological balance and improve the quality of the habitat; and
- recycle waste material and make full utilization of by-products.

Self-Reliance: In a country of India's size and endownments, self-reliance is inescapable and must be at the very heart of technological development. We must aim at major technological breakthroughs in the shortest possible time for the development of indigenous technology appropriate to national priorities and resources. For this, the role of different agencies will be identified, responsibilities assigned and the necessary linkages established.

Strengthening the Technology Base: Research and Development, together with S&T education and training of a high order, will be accorded pride of place. The base of science and technology consists of trained and skilled manpower at various levels, covering a wide range of disciplines, and an appropriate institutional, legal and fiscal infrastructure. Consolidation of the existing scientific base and selective strengthening of thrust area in it are essential. Special attention will be given to the promotion and strengthening of the technology base in newly emerging and frontier areas such as information and materials sciences, electronics and biotechnology. Education and training to upgrade skills are also of utmost importance. Basic research and the building of centres of excellence will be encouraged.

Skills and skilled workers will be accorded special recognition. The quality and efficiency of the technology generation and delivery systems will be continuously monitored and upgraded. All of this calls for substantial financial investments and also strengthening of the linkages between various sectors (educational institutions, R&D establishments, industry and governmental machinery).

Sketchs of M. Visvesvaraya, Jawaharlal Nehru, and J.N. Tata in this chapter have been prepared by V.N. O'Key, published in Architects of Modern India.



CHAPTER IV

SCIENCE EDUCATION

HISTORICAL BACKGROUND

With a long and chequered history of education and training in pure and applied sciences dating back to over 2,600 years, India has had flourishing tradition of scientific research and technological development. Taxila (6th century BC) one of the earliest universities in the world, attracted students from across the continents. Major fields of study at Taxila included mathematics, astronomy, medicine, surgery and metallurgy. Unfortunately, most of the knowledge was lost during the medieval period. The glorious tradition of original thinking, adventure of ideas and creative innovations was completely snapped.

SCIENCE AND SCIENCE EDUCATION DURING THE BRITISH RULE

The development of modern science in India is not an organic extension of the earlier tradition. It is an implant by the British in a language that was alien to its people. As with other implants, it needed nourishment and nurturing to be absorbed in the society. Science education was lacking and science was looked upon as an appendage thrust by the British for their own benefit.

Until a few decades towards the end of the British rule, the role of science education, scientific and technological research in economic growth and social transformation was rather limited. Only such developments were introduced that did not lead to a conflict with the interests of the colonial power. The only aim of education including that of science education was to turn out men competent to serve the civilian administration. Consequently, science education and research was uneven and patchy with no facilities. Even those few individuals educated in science lacked opportunities for either gainful employment or for scientific research. They could only procure clerical or teaching jobs.

It was only in 1857 that the universities of Bombay, Calcutta and Madras, modelled after the London University, were established. As a concession to the Indian aspirations the foundations for basic sciences were expanded and academic science in the universities received a fillip. It must be stressed that even under such adverse conditions, globally competitive scientific research was carried out by a few scientists like, C.V. Raman, M.N. Saha, S.N. Bose, D.N. Wadia, P.C. Mahalanobis, S. R. Kashyap, Birbal Sahni, S.Ramanujan, S. Chandrashekhar. Many of these were trained in India and carried out their research in Indian universities.

The outbreak of the World War I brought about a radical change in science education and in the pattern of scientific research and technological developments. The colonial government being cut-off from Britain was forced to actively mobilize local resources of scientific and technical personnel to meet wartime needs.

POST-INDEPENDENCE PERIOD: NEHRU'S VISION

Within a few decades of the end of World War I, major colonial empires had disintegrated and India became independent in 1947. It is indeed very

fortunate that Jawaharlal Nehru was India's first Prime Minister. Having witnessed first hand the remarkable developments brought out through the pursuit of science in Europe and particularly in the then Soviet Union, he more than anyone else, realized the crucial importance of science for economic growth and social transformation. Addressing the then National Institute of Sciences (now INSA), Nehru stated, *Who indeed can afford to ignore science today? At every turn, we have to seek it's aid and the whole fabric of the world is of it's making.* He strongly emphasized the inherent obligation of a great country like India with its tradition of original thinking to participate fully in the march of science. It was equally fortunate that in laying the firm foundation of science and science education in the country, Nehru's vision was shared by the then leaders in science who helped Nehru to realize his vision. Raman, one of India's most eminent scientists said, *There is only one solution for India's economic problems and that is science, more science and still more science.* Homi Bhabha, the father of India's atomic energy programme, while addressing the General Assembly of the International Council of Scientific Unions, just before his death, emphasized, *What developed countries have and what developing countries lack is modern science and an economy based on modern technology. The problem of developing countries is therefore the problem of establishing modern science and transforming their stagnant and traditional economy to the one based on modern science and technology.* Bhabha went on to add, *An important question we must consider is whether it is possible to transform the traditional economy to the one based on modern technology developed elsewhere without at the same time establishing modern science in the country as a live and vital force? If the answer to this question is in the negative and I believe our experience shows it to be so, then the problem of establishing science as a live and vital force is an inseparable part of transforming an industrially underdeveloped country to a developed country*. In the context of establishing modern science and technology as a live and vital force, the importance of science education cannot be over-emphasized. Indeed, science education plays a crucial and pivotal role in the alchemy of scientific research and technological innovations.

While delivering the convocation address of Allahabad University in 1946, Nehru said, *It is science alone that can solve the problems of hunger and poverty, of insanitation and malnutrition, of illiteracy and obscurantism of superstition and deadening customs, of rigid traditions and blind beliefs, of vast resources going to waste of a rich country inhabited by starving millions*.

Policy Frame

The vision of Nehru of India becoming a beacon spreading to the world not only the message of Buddha and Gandhi of peace and universal brotherhood but also that of science and technology, was translated into working plans through a policy frame that has evolved over the years. The very constitution of the Republic of India (seventh schedule) squarely puts the responsibility for coordination and the determination of standards in the institutions of higher learning and research on the central government, its responsibility also includes central universities, Indian Institute of Science, Institutes of Technology and institutes of national importance declared by the parliament. The constitutional amendment of 1976 places education including science and technology education in the concurrent list which implies the joint responsibility of the central and the state governments. The Government of India has evolved a machinery to discharge these obligations by designating Ministry of Human Resource Development to function as an administrative ministry and by establishing the University Grants Commission and the All India Council for Technical Education, by acts of parliament to superintend the functioning of higher education in science and technology respectively.

Over the years, the Indian parliament has adopted major policy statements relating to higher education and S&T development. These developments have been largely guided by the Scientific Policy Resolution of 1958, one of the most comprehensive science policy documents ever approved by any legislative body in the world.

The parliament approved in 1968, the Technology Policy Resolution, which states that research and development together with S&T education and training of a high order will be provided a pride of place. Basic research and building of the centres of excellence will be encouraged. The quality and efficiency of S&T generation and the related delivery system will be continuously monitored and upgraded. The policy statement calls for strengthening linkages between educational institutions, R&D establishments, and industry and government machinery.

The central government has periodically constituted National Commissions on Education to assess the system of education and for recommending ways and means to diversify, improve and update the system, consistent with the changing environment. Some of the commission's reports were translated into National Policies on Education. Thus the National Commission on Education of 1964 chaired by D.S. Kothari resulted in the preparation of the National Policy of Education in 1968. In 1986, the national Policy was suitably modified, amended and updated. This was further modified in 1992 in the light of Ramamurthy Committee's report covering a whole range of operational, financial and technical issues. The statements emphasize education to be a unique investment for the present and the future, with emphasis on equal access on requisite merit, mobility of students and faculty and networking of educational institutions, R&D establishments, greater autonomy and accountability, relevance of curricula, excellence in research, and mobilization of resources. Thus the statement first made by the Kothari Commission that *the destiny of this country is shaped in the classrooms and laboratories of schools, colleges and universities* is re-echoed.

India has committed whole heartedly to science and has provided the necessary policy support for S&T humanpower development. There is also a systematic planning process in place. The policies and plans have helped India develop a vast infrastructure for higher S&T education, and have provided the second largest manpower in the world, with the best in the system comparable to the best anywhere in the world. However, inadequate understanding of the spirit of the recommendations has led to over-centralisation of authority, bureaucratization by controlling agencies and over-dependence on government support and intervention. The system has become too large and monolithic to ensure quality and accountability.

Growth of the System of Science Education

Recognizing the crucial role played by S&T in the process of economic growth and social transformation, major emphasis was laid on higher science education during early years of Independence. Thanks to the political leadership, conducive policy support and substantial investment, India today possesses one of the oldest, the largest and the most diverse infrastructure. For S&T education and training several institutions comprising the Indian Institute of Technology (IIT's), Indian Institute of Science (IISc), about a dozen institutes of national importance, two hundred and odd universities, and over 8,000 colleges, exist. This infrastructure has already made a substantial impact on the country's scientific, industrial and economic development. There has been impressive development since Independence in various fields such as agriculture, industry, atomic energy, space programmes, manufacturing, and health care.

More than the creditable performance of the S&T personnel in India, the performance of Indian Diaspora cultured in our colleges and universities

has been highly impressive. S&T personnel from India are highly sought after and respected in the countries of their adoption. Some of the academic research institutions such as IISc, Bangalore; TIFR, Mumbai; IITs and a few universities such as Delhi, Jawaharlal Nehru University, Poona, Banaras Hindu University, Varanasi, Central University, Hyderabad; and Jadavpur., have developed global reputation and attract increasingly large number of students from South East Asia, Middle East and Africa. The best products of the Indian system are comparable to the best anywhere in the world, although of course the average product is of a poorer quality. Indeed, Indian S&T personnel have assumed leadership role in areas such as statistics, chemical engineering, biochemistry, information technology, biotechnology, advanced materials and are prominently visible in a number of advanced countries.

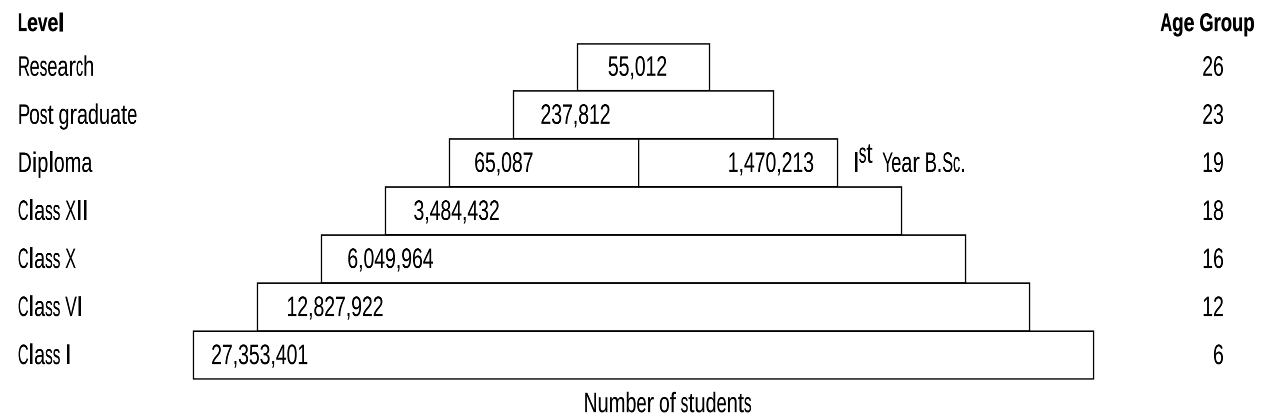
Everything is not, however, fine and rosy about India's science education system. Despite the fact that India today has the second largest education system, it has still to meet the basic needs and aspirations of its billion people. The level of illiteracy still hovers around 35%. The access to science education is on the average around 30%. There is much to be desired in relation to the quality and relevance of higher science education.

Fortunately, India has recognized too well that only by competing successfully in the globally interdependent economy through its S&T humanpower that the living standards can be raised and the hopes of its people met. It has realized that it is through its reformed, updated and restructured higher science education and training system that the country can advance economically. After an almost explosive growth in the S&T system, at the beginning of the new millennium, India is on the threshold of restructuring and updating its science education system so that the tremendous promise and creative abilities of its talented humanpower could enable the country to redeem its tryst with destiny.

During the last fifty years, every aspect related to science education, whether it be student enrolment, number of educational institutions, and the number of teachers have recorded ten-fold growth. As science education is a continuum, it is necessary to consider its growth and its consequences right from the school level.

Science is taught at lower secondary level as an integrated whole than as a compartmentalized discipline. Discipline-oriented teaching and learning commence at 11th and 12th standards corresponding to the age group 16-18 years. The educational pyramid for a typical year (1993-1994) is shown below.

Educational Pyramid 1993- 94



Student enrolment at every level has been increasing at around 7-10 per cent each year.
These figures may give some idea about the numbers involved in the system at the beginning of the 21st century.

Although, the actual numbers are large, the gross enrolment ratio namely the total enrolment at a given level divided by the population of the concerned age group is considerably low as compared to the corresponding figures for a developed country such as USA as shown in the following table:

system continues to grow to achieve gross enrolment ratios comparable to those in the U.S.A. This problem underscores the urgent need to restructure educational system to make it more flexible, more accessible as also to use mass communication technologies for imparting education.

Gross Enrolment Ratios %

	Primary		Secondary		Tertiary				Tertiary 1995	
	1965	1995	1965	1995	1965	1975	1985	1995	Male	Female
India	74	100	27	49	5	9	9	7	8	5
U.S.A	100	102	90	97	40	57	58	81	75	92

Looking at the educational pyramid, one finds that within the age group 5-18, corresponding to classes I-XII, nearly 50% of the population remains out of schools. In the age group 17-18 years, the access to education is barely 20-30%. Besides lower access there are gender and regional disparities. Further, due to rapid growth in education starting from extremely low access at the time of Independence, student

In much the same way, science education at tertiary level (college level) has been expanding almost exponentially. Indeed since Independence, the enrolment in the science stream increased from 127,200 in 1950-51 to the present level of over one million. The following table shows the year-wise enrolment and the graduate degree awarded in natural sciences.

Enrolment to Science Courses and First Degree Awarded in Natural Sciences

YEAR	Enrolment in Science Stream		Degree Awarded	
1982-83	623,545	(19.9) *	112,075	(17.97) **
1983-84	653,092	(19.7)	115,085	(17.62)
1985-86	703,467	(17.9)	124,328	(17.60)
1989-90	802,525	(19.7)	134,366	(16.74)
1991-92	902,221	(19.7)	140,222	(15.57)
1998-99	1,105,621	(19.7)	170,225	(16.20)

* Percentage of total enrolment; ** Percentage of passing at B.Sc. level.

population at every level constitutes a highly mixed lot such as first generation students mixing with students having several generations of educational background. In addition students are drawn from extremely widely varying social, economic, and cultural backgrounds. These are of course problems of growth itself. One can only imagine the numbers involved, the size of the infrastructure necessary and the resources required to cope with the numbers if the

A critical analysis of these data is very revealing. In the first instance, one is alarmed by the high level of failures and dropouts. One sees that on the average, the number of students who successfully complete their degree is barely 14-18%. This implies that nearly 82-85% students either drop out or fail to pass. Indeed large dropouts and failures are unique and distinctive features of the Indian education system. This constitutes a tremendous loss

of public resources. Even if education is considered as an industry, there is a compelling reason for us to critically examine the causes of massive dropouts and failures and evolve remedial measures.

A look at the table also shows that besides low access to education at this level, the actual numbers enrolled into the system has been increasing. It may however be well to appreciate that the percentage of students opting for science after their secondary examination dropped from 32% in the early 1950's to barely 19.7% in recent years. It is not merely the decrease in the percentage that is worrying but the fact that 32% in the early 1950's were from the topmost rung, in contrast to the present day 19.7% from lower middle level. Both these facts indicate that young students, particularly the brighter ones amongst them, are drifting away from science. This is a matter of grave concern. This trend is also indicated by the choice exercised by the National Talent Search Awardees. Out of 750 awardees, hardly 100 opt for science and only 15-20 go up to the M.Sc. level. These figures indicate that students do not opt for science as a first choice but as a last resort, implying an influx of a large number of unmotivated and uninterested students in higher science education.

Ideally, one would have liked a situation where a large number of talented students are motivated to seek a career in science and one then selects a smaller number namely those who demonstrate a creative bent of mind so essential for career in science. To makes matters worse, nearly 88% of the students who opt for science after higher secondary level are taught in affiliated colleges which are rather ill-equipped, over-crowded and poorly staffed. In these colleges, laboratory and library facilities are woefully inadequate. In such an atmosphere, it is impossible for students to experience excitement of doing science and get motivated to undertake science as a career. As at other levels, the access to education at the degree level is also very low in comparison to the access available in advanced countries.

Enrolment Data at the Tertiary Level

	Number of Tertiary Students (Millions)					Number of Tertiary Students Per 100,000 Population			
	1975	1980	1985	1990	1995	1980	1985	1990	1995
INDIA	3.00	3.50	4.40	4.95	5.70	5.15	5.62	—	6.13
U.S.A.	11.10	12.10	12.20	13.70	14.20	5,311	5,068	5,591	5,339

The above table shows that not only the gross enrolment ratios are low in India but also even the actual numbers are lower at the tertiary level as compared to those in the U.S.A.

In tune with the increase in the enrolment at the college and the university level, the number of institutions imparting science education at the degree and the post graduate level has also been increasing over the years.

Growth in Educational Institutions

YEAR	Universities	Deemed Universities	Colleges	Enrolment (Million)
1976	105	9	4,317	2.40
1980	116	12	4,722	2.75
1985	136	17	5,816	3.10
1990	150	29	7,346	4.92
1995	168	36	8,613	6.40

On an average a university seems to cater to roughly 40-50 colleges and 20,000–30,000 students. However, there are a number of universities which supervise 200–300 colleges and have enrolment in the range of 200,000 – 300,000 students.

The following table gives the doctoral degrees awarded by the Indian universities between 1982-94.

The resources for science and technical education are provided entirely by the state and central governments. This total dependence on government support and intervention has skewed the system and has introduced a number of unhealthy trends. A critical analyses of the above and related data have brought out major issues that need to be addressed if the higher education system is to turn out highly qualified, skilled and motivated youth with whose help the country is to make important economic strides.

Number of Doctoral Degrees Awarded

	82-83	84-85	86-87	88-89	90-91	91-92	93 -94
Science	2,893	2,922	2,814	3,044	2,950	3,386	3,504
Engineering	511	509	603	586	620	323	348

This table is indeed very revealing. It shows that although student enrolment and number of universities have increased, the number of research degrees awarded in natural sciences has almost stagnated, whereas in engineering and technology, the numbers have actually declined.

Finally we may look very briefly at the S&T humanpower data. It was around 4.8 million in 1991. The number of S&T personnel has been increasing at the rate of 6% per year and today it stands around 7 million.

It may be useful to look at the resources available to operate such a large system. In the National Policy on Education of 1968, 6% of the GDP was recommended to be spent on education, but this level of investment has continued to be a mirage. In fact, allocation to education as a percentage of GDP has declined slightly in recent years to stand at 3.5%. The share for higher education in general and science education in particular has declined to 1.0% and 0.2%, respectively. This figure (0.2%) appears far too small when compared to the corresponding figures in advanced countries, namely U.S.A. (1.6%), U.K. (1.4%) and Japan (1.04%). It is a matter of serious concern that investment on each student has nose-dived from Rs. 850/- per year in the 1960's to Rs. 350/- per year (at standard prices in 1990). The allocation for equipment and library in most of the colleges is measly.

Major Areas of Concern

India has realized that in the emerging global scenario — wherein intellectual property will be highly valued and rights will be fiercely exploited and zealously guarded — the only way to improve the nation's competitiveness is through better and more productive science and technical education and flourishing scientific research and technological development. It is clearly understood that the world is passing through a transition from international relations being shaped by military might and political considerations to the one in which they will be increasingly determined by scientific competence and technological capabilities. It has more than understood that the arms race of yesteryears has yielded place to technological Olympiads and that military aggression has been replaced by economic exploitation. It is recognised today that, as never before, the competitive advantage of a nation will be increasingly determined by the quality and the number of its S&T humanpower. The experience of the last 50 years has also underlined that the intellectual raw material available to it in the form of young boys and girls is inherently talented, analytical and motivated and comparable if not better than that avail-

able elsewhere in the world. What needs to be done now is to put in place a system of highly productive, exciting and stimulating science education system — flexible and accountable, diverse and yet focused, well funded and properly managed so that these young boys and girls flourish and deliver the goods.

A critical analysis of the data presented earlier has thrown a number of areas of concern that need to be addressed squarely and urgently so that the appropriate system which not only responds to the changing global environment but also provides a future direction is evolved. It appears that India has arrived at the most opportune time to restructure its vast educational system, having passed through a phase of massive expansion.

The major issues that need to be faced are:

- over-centralization, lack of autonomy and flexibility and lack of accountability,
- access to education, removal of gender and regional disparities,
- high rate of dropouts and failures,
- shying away from science of particularly brighter young boys and girls,
- poor quality of production and lack of relevance,

The answers to the above are to be sought by:

- providing equity and promoting excellence, and
- integration of science and technology education and integration of education and research.

> ONE THING IS CERTAIN; YESTERDAY'S EDUCATIONAL SYSTEM WILL NOT MEET TODAY'S AND EVEN LESS TO THE NEEDS OF TOMORROW.
>
> D.S. KOTHARI

Some Initiatives

Educationists in India have identified the areas of concern mentioned above and have responded to them by certain moves. This section describes very briefly the steps taken.

Use of IT in Education: The role of Information Technology (IT) as an instrument for progress and development has been acknowledged widely.

The use of IT tools in teaching will make the learning process considerably simple and affordable. For a large and developing country like India, technology such as Distance Learning needs to be used in a major way to address the problem of limited educational material and resources. A number of projects have been sponsored in collaboration with leading institutions like IITs, IISc, Indira Gandhi National Open University (IGNOU), Nation Council for Science and Technology (NCST), and Birla Institute of Technology and Science (BITS), Pilani, with its long-term objective being promoting both IT based general education and IT based education itself. IGNOU has several IT enabled courses and is further promoting this culture. National Council of Educational Research and Training (NCERT) has set up a National Centre for Computer-based Education to promote training and development of teachers and teacher-educators. The centre will eventually sustain development of school teachers with a culture of resistance to change and provide schools with IT-based inexpensive learning materials in support of the curriculum.

Education Through People's Science Movement: One of the significant leads taken a few decades ago concerns people's science movement (PSM) and education through it. The role of PSM is not only restricted to communicating and simplifying science but also to question every aspect of science-related activities, in particular S&T issues involved and intervening wherever necessary with people's participation.

An outcome of the PSM was the development of the Hoshangabad Science Teaching Programme. Students' active participation in the process of

education was a unique feature of this endeavour. Although it marked a significant deviation from the conventional system and proved effective, it has not yet been absorbed into the formal system. PSM has grown and spread all over the country and has led to the upsurge known as *Bharat Gyan Vigyan Jatha* and has helped considerably to create the necessary social ethos for absorption of science and scientific temper in the society.

Exploratory - An Experiment in Learning by Doing Science: A unique institution called Exploratory has been developed at Pune by a few dedicated educators. Exploratory is neither a school or college laboratory nor a museum but is a place where school and college children can explore and experiment, invent and innovate and design and fabricate. There are no teachers in the exploratory but highly experienced guides who explore along with the students the basic concepts in science through carefully designed activities. The purpose is to enable children to learn science by participating in the process of science. The exploratory promotes keen and careful observation, excites curiosity, encourages children to ask questions, question the answers and enables them to generalize and discover.

Although the formal system of science education has not yet adopted the exploratory way of learning science, exploratories are being set up all over the country.

> WE MUST OVERHAUL THE SYSTEM OF SCIENCE EDUCATION IN THE COUNTRY TO BASE IT ON KNOWLEDGE AND CREATIVITY AND NOT ON MEMORIZING AND EXAMINATIONS
>
> ATAL BEHARI VAJPAYEE

Navodaya Vidyalayas: Navodaya Vidyalayas were conceived in 1986 by Rajiv Gandhi, former Prime Minister of India. The scheme aims at setting up well equipped well staffed schools in rural areas, almost one in every district to provide better quality science education to the talented children. These Navodaya Vidyalayas also serve as a resource centre and a pacesetter for the other schools in the region to follow. These Vidyalayas, 425 in number as of today, also aim at promoting excellence and removing disparities.

Proposal for Restructuring Undergraduate Science Education: National Planning Commission appointed a Committee to suggest restructuring of undergraduate science education. The Committee has recommended a three-tier approach to revitalise science education at the undergraduate level.

Although the suggestions have been hailed by the entire scientific community, these have not yet become a part of the formal system.

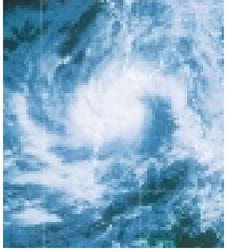
UGC's Efforts in Promoting Excellence: In recent years the UGC has launched a large number of programmes aimed at promoting excellence. These include:

- autonomous colleges
- faculty improvement programmes
- academic staff colleges.
- centres for advanced studies
- curriculum development councils
- career development programmes
- support for strengthening infrastructure in S&T and removal of obsolescence in the universities
- identification of universities with a potential and supporting them to become comparable with the best anywhere.

Inter-University Centres: One of the most innovative steps taken by the UGC for promoting excellence was the setting up of Inter-University

Centres equipped with most modern experimental facilities or providing access to national facilities such as accelerators, nuclear reactors, and synchrotron radiation source, to students and teachers from various universities. Nuclear Science Centre at Delhi, Inter-University Centre for Astronomy and Astrophysics at Pune and Inter-University Consortium for the Department of Atomic Energy Facilities with headquarters at Indore have already been set up and have been extremely useful.

Advance Centres for Science and Technology (ACST): A few senior scientists and industrialists have proposed setting up advanced centres for science and technology. These are composite science and technology education and research centres. They seek to integrate education and research, science and technology, pure and industrial research. These centres will provide a 5-year integrated programme leading to either an M.Sc. or M.Tech. degree. The students will be given a common course in the first year, aimed at ensuring good grounding in physical concepts, equipping them with mathematical techniques and statistical procedures and exposing them to the current excitement in life sciences. A large menu of courses will be offered in the second and the third year from which students can choose, in consultation with the faculty advisors, such courses that would suit their aptitude and abilities. At the end of the third year there will be a test conducted to assess students' aptitude and ability to pursue basic or applied research. The fourth and the fifth year will be for specialization in chosen fields. It also provides for an internship programme of one year in the related industry for applied stream students and in reputed research laboratories for basic science stream students. The faculty will be carefully chosen and encouraged to forge strategic alliances with the industry and will be expected to remain at the frontiers of science and at the cutting edge of technology. Another distinctive feature of the programme is that the beneficiaries of the products of the system, namely the industry, national laboratories, and government science agencies, will participate in the management, monitoring and funding of ACST. It is gratifying to note that UGC has included the proposal for setting up ACST in the tenth five-year plan.



CHAPTER V

SCIENCE OLYMPIADS

The National Board of Higher Mathematics (NBHM) of the Department of Atomic Energy (DAE) initiated activities leading to India's participation in the International Mathematics Olympiad (IMO) from the year 1989. The need for a similar National Olympiad Programme in basic sciences was recognized at the same time in several quarters. It was felt that with a large base of quality human resources in science, the country must also participate in the International Olympiads in physics, chemistry and biology.

In 1997-98, Homi Bhabha Centre for Science Education (HBCSE), a National Centre of the Tata Institute of Fundamental Research (TIFR), Mumbai and the Indian Association of Physics Teachers (IAPT) jointly took the initiative in starting the Physics Olympiad Programme. Next year, HBCSE took steps to extend the programme to chemistry and biology. IAPT came forward to extend its wide network facility in conducting examinations in chemistry and biology. These moves received strong support and encouragement from the DAE, Department of Science and Technology (DST) and the Ministry of Human Resource Development (MHRD) of the Government of India. India sent its first team to International Physics Olympiad (IPhO) in 1998, International Chemistry Olympiad (IChO) in 1999 and International Biology Olympiad (IBO) in 2000. The good performance of the Indian teams right in the first few years of participation helped in consolidation of the programme. India hosted the International Mathematics Olympiad in Mumbai in July 1996. Five years later, India hosted the 33rd International Chemistry Olympiad (IChO) in Mumbai from July 6 -15, 2001, just 3 years after its entry in the IChO.

> THE QUALITY OF A UNIVERSITY IS ALWAYS IN DIRECTION PROPORTION TO THE QUALITY OF ITS TEACHERS.
>
> JAWAHARLAL NEHRU

INDIAN NATIONAL OLYMPIADS

(in Mathematics, Physics, Chemistry and Biology)

The Indian National Olympiad examinations in different subjects (INMO, INPhO, INChO, INBO) are held between the end of January and beginning of February annually at a dozen or more centres in the country. They are the most challenging tests available in India at the pre-college level, patterned after and comparable to the high academic level of the International Olympiads. The National Science Olympiads also include a serious experimental test, a feature absent even in the best entrance examinations in the country for entry to professional courses (engineering, medicine, computer science) after the senior secondary school. Eligibility to appear for the Indian National Olympiads is decided on the basis of an all India examination — the Regional Mathematics Olympiad held in December every year and the National Standard Examination in Physics, Chemistry and Biology held in November each year. These

first stage examinations are held at about 20 centres in mathematics and at a very large number of centres in the case of sciences. About 25000 students enroll for the first stage National Standard Examination in Physics, and a somewhat lower number in other subjects. Out of these, about 200 to 300 students are selected to appear for the National Olympiads. On the basis of their performance, the top 30 to 35 students are short-listed in each subject. These are the National Olympiad winners/awardees. For these awardees, HBCSE organizes training camps each summer in May-June. The Olympiad effort of HBCSE in physics, chemistry and biology and that of NBHM in mathematics involves a training programme assisted by a large number of resource persons invited from different parts of the country. Special Olympiad laboratories have been developed at HBCSE in the three science subjects for training in conducting experiments. Teams of 6 students in mathematics, 5 in physics and 4 each in chemistry and biology are selected at the end of camps to represent India at the International Olympiads every year.

International Olympiads

The International Olympiads are the world's unique and most challenging academic competitions for young college students and are individual events. The medals (gold, silver and bronze), honours, special prizes, are allocated on the basis of individual scores using some agreed criteria usually laid down in the statutes of the particular Olympiad. The Olympiads are festive occasions — a celebration of science or mathematics at its best by its young participants and their teachers. Excursions, cultural programmes and other social activities are an integral part of every International Olympiad. The aims of International Olympiads are not only to encourage young students to strive for excellence in their subjects, but also to promote friendship among students, teachers and scientists from various parts of the world.

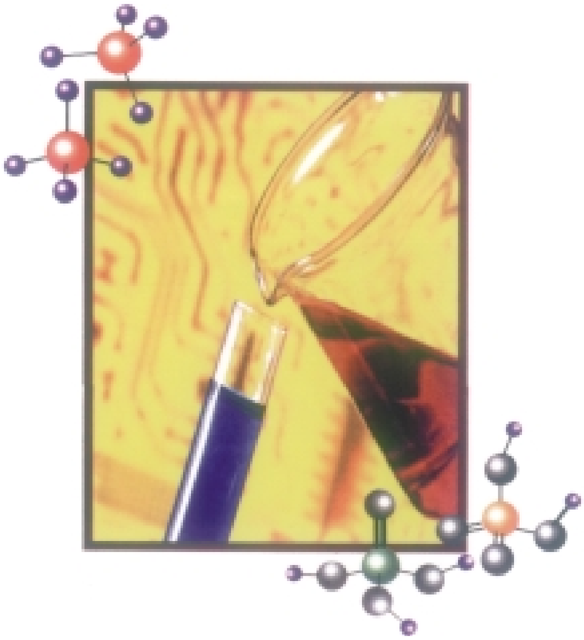
The International Olympiads in mathematics, physics and chemistry started three to four decades ago. IMO is the oldest; it started in 1959; IPhO in 1967 and IChO in 1968. The IBO is relatively recent; it started in 1990. Their genesis lies in the early initiatives in East European countries and the former USSR which laid strong emphasis on mathematics and science in their school syllabi. Gradually, the movement picked up, with more and more countries participating each year. In 2001, eighty-three countries took part: IMO (83), IPhO (65), IChO (54) and IBO (38). In addition to the contesting countries, a few observer countries send their representatives with a view to participating in future. The syllabus for IMO is, broadly speaking, pre-calculus mathematics — number theory, combinatorics, geometry and algebra. The syllabus for IPhO encompasses all parts of classical physics including elementary relativity and modern physics but not formal quantum mechanics.

Performance of Indian Teams at the International Science Olympiads (1999-2001)

Subject/No. of participants sent	Year 1999	2000	2001
Mathematics	3 Silver	5 Silver	2 Gold
(6 students)	3 Bronze	1 Bronze	2 Silver 2 Bronze
Physics	4 Silver	2 Gold	3 Gold
(5 students)	1 Bronze	2 Bronze 1 Merit	2 Silver
Chemistry	2 Silver	2 Silver	1 Gold
(4 students)	2 Bronze	2 Bronze	3 Silver
Biology	No	1 Silver	1 Gold
(4 students)	participation	3 Bronze	3 Silver

The syllabi for IChO and IBO are vast and for bidding, which is why it is a practice in IChOs to send out a set of Preparatory Problems to all participating countries several months before the contest. In IBO, the areas to be stressed in the laboratory contest are announced one year in advance.

There are several other subjects in which International Olympiads are organized. Of special mention is the International Astronomy Olympiad. This is so far restricted mainly to the countries of the former USSR. The Astronomy Olympiad Programme is supported by the ISRO and the Astronomical Society of India. Indian teams have started participating in the Astronomy Olympiad from 1998 and their performance has been highly commendable. There is also another important Olympiad, namely the International Informatics Olympiad in which our country is yet to participate. One Observer is likely to participate this year and the regular Indian participation may begin next year. Some private Olympiads (i.e. those in which teams are not officially sponsored by the respective governments also exist, as for example, in Robotics).



The logo of 33rd International Chemistry Olympiad, Mumbai, India 2001.



The winning Indian team at the 33rd International Chemistry Olympiad, Mumbai, July 1-15, 2001.

Hosting of International Olympiads by India

It is a tacit obligation of every participating country to offer to host an International Olympiad sometime. India hosted the 37th IMO (5-17 July, 1996) in Mumbai. 75 countries participated in this event with 424 contestants. NBHM (DAE) and MHRD provided financial support. The event was a great success and attracted much attention.

More recently (July 6-15, 2001), India hosted the 33rd IChO in Mumbai. Fifty-four countries (with 210 contestants) and 6 observing countries participated in the event. India's ability to hold this mega event so early after its entry into IChO and at a short notice of less than a year received much acclaim from the IChO community. The 33rd IChO has resulted in a tremendous mobilization of expert resources for the chemistry Olympiad activities in India. Some of the top chemists of the country have became excited about the programme and are willing to work for it. As Indian teams are doing well in physics, a similar exercise is desirable in this subject as well.

No student in any subject has returned without a medal/honour in the last four years since our participation in the Science Olympiads began. This is a remarkable achievement for any country, especially, in its early years of participation. The overall performance of Indian teams can be said to be commendable. In Physics, however, Indian teams are giving splendid performance for the last two years. The national rankings are unofficial and discouraged at many Olympiads. As an indicator, however, in terms of aggregate scores, in the year 2001, India ranked 7th out of 83 countries in mathematics, 4th out of 65 countries in physics, 7th out of 54 countries in chemistry and 6th out of 38 countries in biology. This is the best performance of our teams so far.

Incentives and Awards

The incentives/awards in the current Olympiad scheme in India differ from subject to subject. However, a major incentive, namely the *Kishore Vaigyanik Protsahan Yojana* (KVPY) Fellowship of DST is common to all subects. All the 19 students (6 in mathematics, 5 in Physics, 4 each in chemistry and biology) who are members of the Indian teams at the International Olympiads automatically qualify for KVPY Fellowship (Rs.3,000/- p.m. + Rs 6,000/- p.a. contingency grant plus a nurture programme) provided they continue to pursue careers in science. An important career incentive is offered by BARC for the physics and chemistry students of this set. The 5 students in physics and 4 in physics and 4 in chemistry are offered direct admission to BARC Training School five years in advance, provided again that they pursue undergraduate and post graduate careers in sciences.

Students who are selected for the Indian teams in physics, chemistry and biology receive an award of Rs.5,000/- each at the end of the training programmes. The Award scheme in mathematics is slightly different. All the participants in the training camp are entitled to an award of Rs.5000/- each and students of the Indian team who received medals at the Olympiad receive further cash prizes. In the year 2001, the Government of India have announced an award of Rs.5,000/- to each of the 19 students of the Indian teams who have received medals at the International Olympiads.

Despite these incentives and awards, most Olympiad students opt for professional courses in computer science, engineering, medicine, and so on. A systematic post-Olympiad follow-up of Indian students has not been undertaken so far —it needs to be done. Only a few of them have taken up careers in basic sciences/mathematics. But we are also aware of many more Olympiad students who continue to have strong interest in pure sciences and desire to turn to them sometime later after their basic professional degree — a fanciful thought perhaps but not wholly unrealistic. A couple of mathematics students are known to have done that. It is too early to assess if the Science Olympiads in India will help attract at least a reasonable number of Olympiad winners to take up a career in science. An assured career scheme is being mooted in some quarters that guarantees jobs to these students in good institutions of the country well in advance, provided they pursue careers in science . This scheme, a kind of extension of the current KVPY, is probably the best that can be attempted to arrest the trend of bright students opting out of basic sciences.

Analysis and Prospects

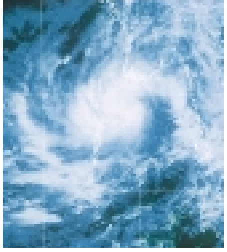
The Olympiads have certainly generated considerable excitement and interest among the meritorious and motivated students of the country. This is evident from the increasing enrolment of students for the first stage examination year after year. A few observations on the positive features of the current Olympiad scenario in India, as also its inadequacies and possible measures to overcome them are given below.

- The Government of India is very supportive of the Olympiad Programme, with three major ministries (DAE, DST and MHRD) providing encouragement and financial aid to the activities.

- The senior secondary syllabi in India in the science subjects are by and large globally competitive.
- The entrance examinations for prestigious professional courses (in engineering, medicine, computer science, and others) in the country (e.g. IIT—JEE) are quire demanding. Students preparing for these examinations develop good skills in solving problems in many if not all the topics of the Olympiad syllabi.
- IAPT has played a significant role in the success of the Science Olympiad Programme in India. The National Standard Examination in Physics which IAPT has been conducting for many years has become an excellent first stage examination for the Olympiad programme. Indeed, one of the most important fall-out of the science Olympiad activities in India has been the strengthening of IAPT and the formation of new teacher associations along the same lines, namely, IACT and IABT.
- An important feature of the Indian Olympiad scene is the emergence of HBCSE (TIFR) as the nodal centre of the country for the Olympiad programmes in science and mathematics. Besides being a venue for training (especially, laboratory training) of the National Olympiad awardees in different subjects, the Centre plays a crucial role in mobilization of expert human resources from leading institutions of the country for Olympiad activities.
- The National Olympiad Programme, pitched at the level of senior secondary and above has no organic connection with the mainstream school education in India. The secondary school education in the country rarely gives any opportunities of solving difficult problems or performing good experiments even to a limited number of good students. What is perhaps needed is an All India Junior Olympiad in Mathematics and Science pitched at the Class IX level. This will not only improve the input quality of students for the National Olympiads but also promote an Olympiad culture at least in some of the schools of the country.
- The present incentives for Olympiad students are not enough. In some countries, the national Olympiad winners automatically qualify for admission to courses in the coveted institutions. In India, however, the national Olympiad awardees have to concurrently prepare and appear for a large number of entrance examinations.
- Training of the Olympiad students is insufficient. It happens only once at HBCSE, in the summer prior to the International Olympiads. However, training, especially, laboratory training, needs to be started at different stages for longer periods. There is a need to have several zonal Olympiad centers where training in Olympiad kind of problems is provided and experiments could be carried out by local institutions and/or teacher associations.

Most of the limitations of the current Olympiad scene can be corrected with some effort and imagination. The concerned people are seized of the matter and, hopefully in the near future, the Indian Olympiad Programme in Science and Mathematics will become stronger and more comprehensive.

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CHAPTER VI

Engineering and Technical Education

Education in Ancient and Medieval India

Indian education system can be traced to *Vedic* period (prior to 1000 BC) and the Epic period (1000 BC to 800 BC) which comprised *ashrams* (hermitages) of *acharyas* and *kulagurus* (teacher sages). It is believed that teachings included technological skills and science of warfare besides Vedas, languages, logic, philosophy, ethics, politics, and economics. The education system of the Epic period evolved into three types of institutions: *gurukulas*, temple schools and the *agrahara* village institutions.

An institution of great fame, Taxila developed in the north-west India (now in Pakistan). With the political influence of Hindus, Persians, Greeks and Kusans, Taxila served as the capital of a number of dominions and through exposure of many cultural influences, acquired a cosmopolitan character. Students came from far off places to study various arts and sciences and medicine. Numerous technical skills such as carpentry, smithy, foundry and weaving were taught at Taxila. South India with a profusion of temples had a lead in the development of temple schools in medieval times.

In India, the Buddhist developed university institutions similar to *stadium generale* several centuries before their appearance in Europe. Among the famous institutions are Nalanda, Vikramshila, Jagaddala, Odantapuri and Ranchi, which gradually disintegrated with the decay of Buddhism in India.

Specifical details of technical and vocational education in medieval India are not available. However, there is ample evidence that vocational skills were highly developed. Elegance and excellence of articles such as fine fabrics of cotton and silk, embroidery, painted and enamelled wares, swords and knives and gold and silver jewellery . are well known. Such high quality could not have been achieved and sustained for centuries without a dependable system of technical education. Broadly three systems developed during that time: pupilage system, hereditary training and training schools.

Early Developments During the British Rule

The development of new technological activities growing out of scientific research in Europe led to the concept that practical skills be taught in special schools in India by the British. Schools were set up for imparting skills which needed sound knowledge of mathematics, science and use of scientific instruments. Land Surveying was given high priority to train surveyors for government works.

The first Survey School on the Indian soil was opened in May 1794 in Madras, now Chennai. Later on, technical education spread to other parts of the country. The Madras Survey School trained only English boys. The 'native Indians' were left out because of political and military implications of survey work. The East India Company feared that survey maps could fall into the hands of their French and

Dutch rivals. Civil surveying was a well-established branch of knowledge in India as it served revenue purposes. Land revenue maps were in vogue much before the British came in.

The General Committee of Public Instruction formed in 1823, comprising British Officers was the only organ to advise the Government on educational matters. This Committee was replaced by the Council of Education and the subject of education in general was brought directly under the control of the Government. The General Committee and later the Council of Education advised the branches of study useful to students for their livelihood. Apart from reading, writing and arithmetic, surveying was strongly emphasized on account of its utility to the British rule. The concept that drawing and surveying be taught at only college level and not at school level gradually emerged in Bengal. From the need to have these subjects taught in colleges to the desirability of Colleges of Civil Engineering was a big step, yet quite logical. Engineering was not yet classified into several disciplines; the term meant engineering for civil purposes as distinct from military functions. The importance of civil engineering as a discipline of education for Indians started receiving emphasis in 1840s with road and canal projects as goals.

Cautley, an army engineer, associated with the construction of Ganga Canal had envisaged the establishment of a school to supply efficient workmen for the Canal Project. James Thomason, Lt.Governor of North-Western Provinces (NWP) had a bigger idea beyond just the canal. He thought of the whole country in terms of surveys, irrigation, navigation, roads, bridges, railways, for all of which it was impossible to provide Britishers. His proposal, in the context of Ganga Canal and the infrastructure, which had already come up to service the project, to establish a Civil Engineering College at Roorkee was accepted by the Governor-General Lord Hardinge. The Roorkee College was established and it started functioning in January 1848 with an army Lieutenant as its first Principal. Within a few years, engineering colleges were established at Kolkata, Chennai and Pune. The Roorkee College was named as Thomason College of Civil Engineering in 1854 in honour of its founder who had died the year before.

Pioneering Initiative: The concept of engineering education through formal instruction in a school or college was unknown at that time even in England. Consequently, the subjects of engineering were not properly classified and structured for teaching. The teachers of Roorkee College within the first 25 years of its inception did the pioneering work in systematizing the teaching of engineering and preparing education material. The printing press of the college played a great role in publishing 17 College Manuals and three volumes of *Roorkee Treatise on Civil Engineering in India*, which became standard texts in other engineering colleges.

Role of Military Engineers in Engineering Education: The Royal Engineers in the Army in India played a major role in influencing, the fortune of Roorkee College and the three other colleges in Kolkata, Mumbai and Chennai. Military engineers were the only type of engineers that came to India with the East India Company. As the Company assumed greater power for governing the country, all technical jobs in engineering and science were entrusted to military engineers. Almost all the PWD officers came from this tribe and engineering education came under their purview. The principals and teachers of these colleges were also army engineers. These men ensured that military was the feeder for admission to these colleges and the colleges, in turn, served the army by running special courses for its officers and other ranks.

The Institution of Universities: On the recommendation of the Court of Directors of the East India Company, Universities of Calcutta, Madras and Bombay were established in 1857, with a comprehensive academic scope. They established faculties of arts, science and law, as well as of

medicine and engineering. The three provincial engineering colleges were duly affiliated to the university of their region but the graduates started receiving university degrees from 1864 onwards .

Winds of Change: Exposed to and enlightened by the industrial development, political thought and education of the West in the 1880s, a growing number of educated Indians wanted India to progress in these areas. Unemployment of the educated Indian youth was on the increase and technical education was regarded not only as a basic requirement for industrialization but also to provide employment. The newspapers with nationalist leaning criticized the Government for not making enough provision for technical education. A mention of the need for technical education became a regular feature of the Presidential addresses of the Indian National Congress Sessions and their resolutions.

The Education Commission appointed in 1882 to review the progress of secondary education also drew attention to the complete neglect of practical studies and job-oriented skills. The Government accepted the recommendations of the Commission and passed a resolution in 1884 providing that every variety of studies should be encouraged to direct the attention of the youth to industrial and commercial pursuits.

As a follow up of 1884 resolution, and as directed by the Viceroy, a memorandum was prepared in 1886 by MacDonnel, the Officiating Secretary of the Government of India. He divided technical education into two classes: university education and school education. The 1886 profile of technical education in the MacDonnel memorandum is given in the following tables.

Enrolment in Four Colleges (1884-85)

NAME OF COLLEGE	University level	School level	Total
Civil Engineering College, Madras (now Chennai)	19	106	125
College of Science, Poona (now Pune)	102	77	179
Government Engineering College, Howrah	42	107	149
Thomason College of Civil Engineering, Roorkee	–	107	107
Total	318	290	608

Enrolment in Survey and Industrial Schools (1884-85)

PROVINCE	Survey Schools		Industrial Schools	
	Number	Enrollment	Number	Enrolment
Madras	—	—	6	249
Bombay	1	21	7	307
Bengal	4	171	5	172
Punjab	—	—	4	93
NW Province	—	—	2	186
Central Province	—	—	19	316
Assam	7	163	1	18
Burma	5	110	1	38
Total	17	465	45	1,379

The policy of the Government was to accept the desirability of technical education with no financial responsibility to spread it, the latter was left to the public. Low grade technical and industrial schools were opened and were run variously by education departments, district boards and privately.

Lord Curzon (Viceroy of India, 1899-1905) thought that India did not have the necessary education base to profit from higher technical education. There were only a few industries in India, mostly owned by Europeans who preferred to employ only Europeans in technical positions.

The Nationalist Opinion: The nationalist opinion to promote technical education was building up. An industrial conference sponsored jointly by Indian industrialists and the Indian National Congress became a regular feature as an adjunct to the annual congress sessions. In the first such conference in 1905, it was impressed upon the Government the desirability of establishing at least one central polytechnic institute for the whole of India and a technical college in each province. Lord Curzon rejected the suggestion as clambering of natives for things they know nothing about. His successor, Lord Minto, was advised that these were harmless platitudes not deserving serious attention.

The *Swadeshi* (of our own country) movement which started sweeping the whole country in the early 20th century led to an urge for *Swadeshi* education too. Many national educational institutions, free from Government control, were established at various places, some of which also imparted technical education. The next Viceroy, Lord Hardinge, was more inclined to give weightage to technical education. Prominent among the institutions opened with private initiatives were the Indian Institute of Science, Bangalore, which started functioning in 1911 and the Banaras Hindu University in 1916 in which a College of Engineering was started in 1919.

The Period of World War I and the Period between the Two Wars: Prolonged wars ironically fuel industrial activities. Although no concrete progress was made in technical education during the World War I , a change in approach following the reports of the Indian Industrial Commission (1916) and the Calcutta University Commission (1917), led to developments in technical education in the subsequent years. With the Government becoming more responsive to public demand, the technical education profile began to slowly improve. Prior to 1919, the number of higher or university level technical or engineering institutions was only five , this rose to 21 in 1939 and the number of diploma schools increased from eight to 23. Nationalist will, private enterprise and Government assistance all played their parts in this change. To mention a few of the institutions which were established, Harcourt Butler Technological Institute, Kanpur (1920), Indian School of Mines, Dhanbad (1926), Maclagan College of Engineering, Lahore (1930), University Department of Chemical Technology, Mumbai (1934), Engineering College in Aligarh Muslim University (1935), Delhi Polytechnic (1941), Laxminarayan Institute of Technology, Nagpur (1943), Alagappa Chettiar College of Technology, Guindy (1944), Department of Engineering in Annamalai University (1945) and three other colleges in Madras Province in Coimbatore (1945), Kakinada and Anantapur (1946).

In 1936-37, the total enrolment for technical education in India was 0.126 million which rose to 0.201 million at the time of Independence.

The Post-War Transition: As the World War II drew to its end, the British Government realized that the era of colonialism was over. A transfer of power to Indian hands became inevitable. The British Government of India, therefore, considered it futile to hold on to its economic and industrial policies to suit the interest of British industry. During the dusk years of its rule, the British Raj decided to release the brakes it had applied for a century to withhold industrial progress. One of the steps was the thinking of technical

education in a big way to provide facilities all over India for higher education in science, engineering and technology comparable to anywhere in the world. The overseas scholarship scheme of 1944 was pursued more vigorously. The Central Advisory Board of Education (CABE) was asked to prepare a report on the post-war educational development in India. In the light of this report, an ad-hoc committee under the chairmanship of N.R. Sarkar was constituted in 1945 to advise on the provision of advanced technical education in India. The Sarkar Committee recommended the establishment of at least four Higher Technical Institutes one in each zone -- north, south, east and west.

A crucial recommendation of CABE was the constitution of a central agency to ensure an all-India coordinated and integrated growth and spread of technical education. The Government of India, thus, established the All India Council for Technical Education (AICTE) to supervise all technical education above the high school stage. The Council had its inaugural meeting under the Chairmanship of Sarkar in May 1946.

Early Developments in Independent India: In pursuance of the Sarkar Committee recommendations, five Indian Institutes of Technology were gradually established betwen 1950 and 1961. The Government of India appointed a Commission under the chairmanship of S. Radhakrishnan to examine the Indian University education -- including technical education -- and to suggest improvements and extensions. The Commission in its report emphasized the need of new types of engineering and technical institutions in India to produce men not only skilled in technology but who were well integrated individuals. It was emphasized that technical education must include elements of general education and engineering courses should have underlying scientific studies. The Commission also advocated closer liaison between engineering colleges and universities so that the colleges would grow vigorously in an atmosphere of higher research in science. Wherever possible, the existing engineering and technical colleges should be upgraded for postgraduate training and research. The Commission further recommended to start, without delay, higher technological institutes to produce much needed engineer-scientists and design and development engineers. The Commission clearly advocated that engineering colleges be not controlled or dominated in their administration by the Government. These and other recommendations led to several developments in the succeeding years. The first year of all undergraduate degree courses were made common in all branches of engineering. Curricula were revised to include general education and basic physical and engineering sciences.

The Structure of Higher Technological Education in India

In the Indian system, the completion of the senior secondary examination is the stage from where higher education begins (ten years of primary and secondary education plus two years of higher secondary education). The first degree, the bachelor's degree is obtained after three years of study in the case of science and liberal arts and four years in the case of engineering and technology. The master's degree programme was of two year's duration earlier but is currently of one and a half year duration. The research degree (Ph.D.) takes variable time but can be completed in three years.

In addition to degree courses in engineering and technology a number of discipline-oriented and certificate courses are also available. Their range is wide, some being undergraduate diploma courses and others postgraduate courses with a duration of one to three years.

The System of Governance of Technical Education: Education is a concurrent subject under the purview of the Central Government as well as the State Government. In addition, statutory bodies like (AICTE) and the University Grants Commission (UGC) have their empowerment by the Acts of

Parliament to regulate higher education. Professional Bodies such as the Council of Architecture, Pharmacy Council of India and the Institution of Engineers (India) have their roles, some of which are well defined and some others not so. The universities and deemed-to-be universities exercise various controls arising out of their statutes.

The Bureau of Technical Education (BTE) in the Ministry of Human Resource Development provides grants to centrally funded institutions such as the Indian Institutes of Technology (IITs), Indian Institutes of Management (IIMs), School of Planning and Architecture (SPA), New Delhi, Technical Teachers Training Institutes (TTTIs), Indian School of Mines (ISM), Dhanbad, and Indian Institutes of Information Technology (IIITs). BTE processes the programmes of these centrally funded institutions, monitors and evaluates them. UGC allocates and disburses funds to the central universities and has the mandate with reference to norms and standards of education in the universities.

AICTE was originally constituted as an advisory body in 1945 for all matters relating to technical education. Although AICTE had no statutory power, it played an important role in the development of technical education in India. In the late nineteen fifties, early sixties and eighties there was a large-scale expansion of technical education. Whereas the earlier growth occurred with the approval of AICTE

The University of Roorkee.



The AICTE has allowed approved institutions offering technical courses leading to diploma, degree and postgraduate degrees 15 per cent seats extra over and above the sanctioned number for foreign students. These seats will be meant exclusively for foreign students.

and the Government of India, the expansion of eighties was brought about primarily in the self-financing sector without the approval of AICTE and the Government of India, and was localized in four States — Karnataka, Maharashtra, Andhra Pradesh and Tamil Nadu. It was in this period that the National Policy on Education (NEP) (1986) envisaged that AICTE be made a statutory body and be vested with the authority for planning, formulation, and maintenance of norms and standards. Even as early as 1964, the Education Commission under the chairmanship of D. S. Kothari had made similar recommendation for proper administration of technical education. AICTE was made a statutory body in 1987, by an act of Parliament, for appropriate planning and coordinated development of the technical education system throughout the country. AICTE functions through its various statutory bodies to comply with the mandate provided by the Act.

Expansion of Technical Education: When India attained Independence in 1947, there were only 38 degree-level and 52 diploma-level engineering/technical institutions with a total intake of 2,500 and 3,670 students, respectively. To carry out development plans, the country required expansion of the system of technical education, especially to provide human power for industries and technical services. The Central and State Governments provided funds to increase the technical education facilities in the 1950s and early 1960s which resulted in the establishment of a large number of Government and Government-aided private institutions in the country. The Government also adopted a policy of heavily subsidizing the technical institutions to

State	Engineering College		Polytechnics	
	Number	Intake	Number	Intak e
Maharashtra	135	35,835	169	34,635
Tamil Nadu	153	31,895	211	43,754
Karnataka	75	26,337	199	36,038
Andhra Pradesh	102	25,435	92	15,895
Himachal Pradesh	02	410	01	180
Assam	03	660	10	1,318
North-Eastern States	05	860	11	1,490
Bihar	12	2,635	28	3,983
Gujarat	20	5,885	39	9,005

attract meritorious students. The aided institutions received 50 to 70% of the capital cost and 80 to 90% of the recurring cost.

Regional Engineering Colleges: A large number of industrial projects were contemplated in the Second Five Year Plan (1965-61). To ensure the supply of trained personnel for these projects, an assessment of demand and supply was made . It was estimated that a shortage of engineers and diploma holders would occur. Therefore, a scheme was formulated for the growth of the existing engineering colleges and polytechnics. The scheme was reviewed for capacity expansion. As a part of this initiative, eight Regional Engineering Colleges (RECs) were established in the first phase. It was decided to have one REC in each of the major states, thus adding up to a total of 17. REC's have a national character and each college is a joint and cooperative enterprise of the Central Government and the State Government concerned.

Private Initiatives: Technical education has always been and continues to be one of the more preferred areas of study with expectations for better career opportunities. During the last two decades, the growing demand for expansion of technical education and the inability of the Government (which traditionally has been establishing and running technical institutions), to meet the social aspirations, has resulted in private initiative to provide the alternatives. In recent years, private registered societies and trusts have established a phenomenally large number of technical institutions. The self-financing technical institutions now account for more than two-third of the admissions to engineering colleges and nearly half in polytechnics.

According to the AICTE the intake in degree and diploma courses in engineering at the time of Independence with the corresponding figures of 1,85,758 and 2,11,894 as on March 31, 2000 (Annual Report for the year 2000) shows an increase in intakes by factors of 74.3 and 57.74 respectively. There is a significant imbalance in the geographical spread of technical education. The above table shows the contrast between selected states which have some of the highest intake capacities with those that have the lowest (as on March 2000).

Shortage of Technical Human Resource: In absolute numbers technical personnel have increased in the country. However, international comparison shows that per thousand population, India has 3.5 S&T personnel, whereas China has 8.1, South Korea 45.9, U.S.A. 55, Germany 76, Israel 76 and Japan 110. Thus India needs several times more S&T personnel if it has to compete globally.

Research and postgraduate education in engineering and technology is confined to only a few institutions. Despite attractive scholarships, nearly 60 per cent of over 19,000 postgraduate seats approved in 191 institutions remain vacant while less than 7,000 complete the courses. Annually less than 400 research scholars complete their Ph.D. in engineering and technology. The low out-turn of postgraduates who constitute the supply source of teachers, is a major concern of technical education system which suffers from 12,000 vacant positions, a number which is growing.

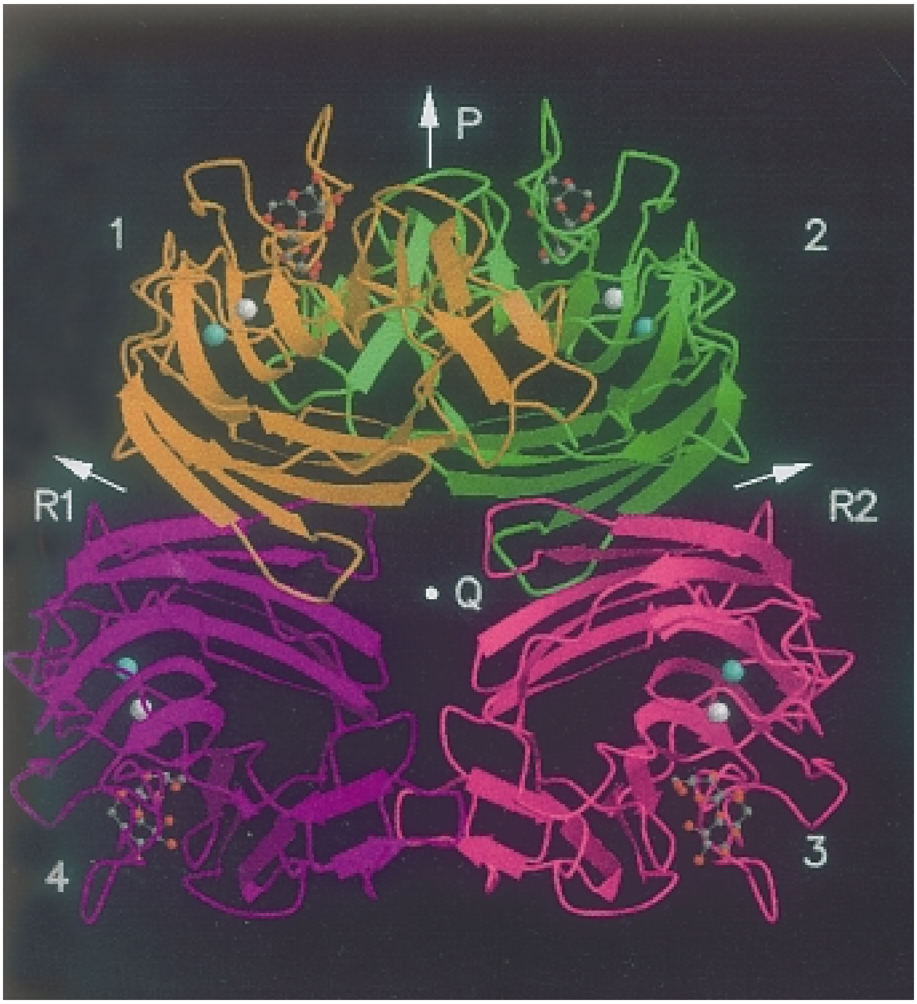
A significant percentage of degree holders in engineering, particularly from better institutions, take up management and administrative jobs or go abroad. This results in a loss of 40 per cent to 50 per cent in some critical areas of technology from IITs and a few other institutions.

To offset this inevitable loss and the need of a much larger number of good institutions of engineering and technology, private initiative is the only option since this national need cannot be fulfilled by public funding. Private initiatives, therefore, have an honourable role to provide opportunities for technical education to a much larger number of students.

Need for a Technical Education Policy

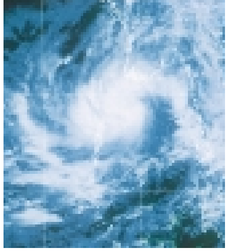
The National Education Policy (NEP) of 1986 addressed to the issues of engineering and technical education in the private sector in a different context. The 1980's saw a phenomenal growth of technical institutions in four states. This sudden increase of technical education, like in adiabatic expansion of a thermodynamic process, resulted in cooling of quality. To arrest the decline in the degree of excellence, as envisaged in NEP, AICTE was made a statutory authority. This response was largely conditioned by the imperatives of damage control rather than the need of control to ensure high norms and standards. Through the years, AICTE has become more effective in fulfilling its mandate flowing from the AICTE Act of 1987. The Act was born in a milieu of distrust of the private sector in the area of technical education. The atmosphere has changed and the private sector has to be encouraged in every way to invest in technical institutions to provide high-quality education. The existing system is a mix of what was designed and what has evolved, both of which need a critical appraisal and review. A new policy initiative is needed which would take into account the inescapable role of the private sector, the emerging technologies, the new modes of knowledge delivery in an electronic environment, the role of Governments and universities, the system of regulations and controls, the market pressure of foreign agencies which are making inroads in the Indian education system, networking of education and research, distance education, the system of accreditation and its international interface and the promotion of excellence and its sustenance.

India urgently needs a coordinated blueprint for technical education, research and development encompassing Governments, private sectors, and research and academic institutions, consistent with the industrial, technological and economic future of the country.



IN SEARCH OF EXCELLENCE

Excellence is a journey and not a destination. In science it implies perpetual efforts to advance the frontiers of knowledge. This often leads to progressively increasing specialization and emergence of newer disciplines. A brief summary of salient contributions of Indian scientists in various disciplines is introduced in this section.



CHAPTER VII

Mathematical Sciences

The modern period of mathematics research in India started with Srinivasa Ramanujan whose work on analytic number theory and modular forms is highly relevant even today. In the pre-Independence period mathematicians like S.S. Pillai, Vaidyanathaswamy, Ananda Rau and others contributed a lot.

Particular mention should be made of universities in Allahabad, Varanasi, Kolkata, Chennai and Waltair and later at Chandigarh, Hyderabad, Bangalore and Delhi (JNU). The Department of Atomic Energy came in a big way to boost mathematical research by starting and nurturing the Tata Institute of Fundamental Research (TIFR), which, under the leadership of Chandrasekharan, blossomed into a great school of learning of international standard. The Indian Statistical Institute, started by P.C. Mahalanobis, made its mark in an international scene and continues to flourish. Applied mathematics community owes a great deal to the services of three giants — N.R. Sen, B.R. Seth and P.L. Khastgir. Some of the areas in which significant contributions have been made are briefly described here.

Algebra

One might say that the work on modern algebra in India started with the beautiful piece of work in 1958 on the proof of Serre's conjecture for n=2. A particular case of the conjecture is to imply that a unimodular vector with polynomial entries in n variables can be completed to a matrix of determinant one. Another important school from India was started in Panjab University whose work centres around Zassanhaus conjecture on groupings.

Algebraic Geometry

The study of algebraic geometry began with a seminal paper in 1964 on vector bundles. With further study on vector bundles that led to the moduli of parabolic bundles, principle bundles, algebraic differential equations (and more recently the relationship with string theory and physics), TIFR has become a leading school in algebraic geometry. Of the later generation, two pieces of work need special mention: the work on characterization of affine plane purely topologically as a smooth affine surface, simply connected at infinity and the work on Kodaira vanishing. There is also some work giving purely algebraic geometry description of the topologically invariants of algebraic varieties. In particular this can be used to study the Galois Module Structure of these invariants.

Lie Theory

The inspiration of a work in Lie theory in India came from the monumental work on infinite dimensional representation theory by Harish Chandra, who has, in some sense, brought the subject from the periphery of mathematics to centre stage. In India, the initial study was on the discrete subgroups of Lie groups from number theoretic angle. The subject received an impetus after an international conference in 1960 in TIFR, where the leading lights on the subject, including A. Selberg partic-

ipated. Then work on rigidity questions was initiated. The question is whether the lattices in arithmetic groups can have interesting deformations except for the well-known classical cases. Many important cases in this question were settled.

Differential Equation

After the study of *L*-functions were found to be useful in number theory and arithmetic geometry, it became natural to study the *L*-functions arising out of the eigenvalues of discrete spectrum of the differential equations. Minakshisundaram's result on the corresponding result for the differential equation leading to the Epstein Zeta function and his paper with A. Pleijel on the same for the connected compact Riemanian manifold are works of great importance. The idea of the paper (namely using the heat equation) lead to further improvement in the hands of Patodi. The results on regularity of weak solution is an important piece of work. In the later 1970s a good school on non-linear partial differential equations that was set up as a joint venture between TIFR and IISc, has come up very well and an impressive lists of results to its credit.

For differential equations in applied mathematics, the result of P.L. Bhatnagar, BGK model (by Bhatnagar, Gross, Krook) in collision process in gas and an explanation of Ramdas Paradox (that the temperature minimum happens about 30 cm above the surface) will stand out as good mathematical models. Further significant contributions have been made to the area of group theoretic methods for the exact solutions of nonliner partial differential equations of physical and engineering systems.

Ergodic Theory

Earliest important contribution to the Ergodic theory in India came from the Indian Statistical Institute. Around 1970, there was work on spectra of unitary operators associated to non-singular transformation of flows and their twisted version, involving a cocycle.

Two results in the subjects from 1980s and 1990s are quoted. If G is lattice in SL (2,R) and {u_t} a unipotent one parameter subgroup of G, then all non-periodic orbits of {u_t} on G_1 are uniformly distributed. If Q is non-generate in definite quadratic form in n=variables, which is not a multiple of rational form, then the number of lattice points x_ with $a < |Q(x)| < b$, $||x|| < r$, is at least comparable to the volume of the corresponding region.

Number Theory

The tradition on number theory started with Ramanujan. His work on the cusp form for the full modular group was a breakthrough in the study of modular form. His conjectures on the coefficient of this cusp form (called Ramanujan's tau function) and the connection of these conjectures with conjectures of A. Weil in algebraic geometry opened new research areas in mathematics. Ramanujan's work (with Hardy) on an asymptotic formula for the partition of *n*, led a new approach (in the hands of Hardy-Littlewood) to attack such problems called circle method. This idea was further refined and S.S. Pillai settled Waring's Conjecture for the 6th power by this method. Later the only remaining case namely 4th powers was settled in mid-1980s. After Independence, the major work in number theory was in analytic number theory, by the school in TIFR and in geometry of numbers by the school in Panjab University. The work on elliptic units and the construction of ray class fields over imaginary quadratic fields of elliptic units are some of the important achievements of Indian number theory school. Pioneering work in Baker's Theory of linear forms in logarithms and work on geometry of numbers and in particular the Minkowski's theorem for n = 5 are worth mentioning.

Probability Theory

Some of the landmarks in research in probability theory at the Indian Statistical Institute are the following:

- A comprehensive study of the topology of weak convergence in the space of probability measures on topological spaces, particularly, metric spaces. This includes central limit theorems in locally compact abelian groups and Milhert spaces, arithmetic of probability distributions under convolution in topological groups, Levy-khichini representations for characteristic functions of probability distributions on group and vector spaces.
- Characterization problems of mathematical statistics with emphasis on the derivation of probability laws under natural constraints on statistics evaluated from independent observations.
- Development of quantum stochastic calculus based on a quantum version of Ito's formula for non-commutative stochastic processes in Fock spaces. This includes the study of quantum stochastic integrals and differential equations leading to the construction of operator Markov processes describing the evolution of irreversible quantum processes.
- Martingale methods in the study of diffusion processes in infinite dimensional spaces.
- Stochastic processes in financial mathematics.

Combinatorics

Though the work in combinatorics had been initiated in India purely through the efforts of R.C.Bose at the Indian Statistical Institute in late thirties, it reached its peak in late fifties at the University of North Carolina, USA, where he was joined by his former student S.S.Shrikhande. They provided the first counter-example to the celebrated conjecture of Euler (1782) and jointly with Parker further improved it. The last result is regarded a classic.

In the absence of these giants there was practically no research activity in this area in India. However, with the return of Shrikhande to India in 1960 activities in the area flourished and many notable results in the areas of embedding of residual designs in symmetric designs, A-design conjecture and t-designs and codes were reported.

Theory of Relativity

In a strict sense the subject falls well within the purview of physics but due to the overwhelming response by workers with strong foundation in applied mathematics the activity could blossom in some of the departments of mathematics of certain universities/institutes. Groups in BHU, Gujarat University, Ahmedabad, Calcutta University, and IIT, Kharagpur, have contributed generously to the area of exact solutions of Einstein equations of general relativity, unified field theory and others. However, one exact solution which has come to be known as Vaidya metric and seems to have wide application in high-energy astrophysics deserves a special mention.

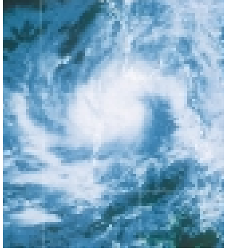
Numerical Analysis

The work in this area commenced with an attempt to solve non-linear partial differential equations governing many a physical and engineering system with special reference to the study of Navier-Stabes equations and cross-viscous forces in non-Newtonian fluids. The work on N-S equation has turned out to be a basic paper in the sense that it reappeared in the volume, *Selected Papers on Numerical Solution of Equations of Fluid Dynamics, Applied Mathematics*, through the Physical Society of Japan. The work on non-Newtonian fluid has found a place in the most prestigious volume on *Principles of Classical Mechanics & Field Theory* by Truesdell and Toupin. The other works which deserve mention are the development of extremal point collocation method and stiffy stable method.

Applied Mathematics

Till 1950, except for a group of research enthusiasts working under the guidance of N.R.Sen at Calcutta University there was practically no output in applied mathematics. However, with directives from the centre to emphasize on research in basic

and applied sciences and liberal central fundings through central and state sponsored laboratories, the activity did receive an impetus. The department of mathematics at IIT, Kharagpur, established at the very inception of the institute of national importance in 1951, under the dynamic leadership of B.R.Seth took the lead role in developing a group of excellence in certain areas of mathematical sciences. In fact, the research carried out there in various disciplines of applied mathematics such as elasticity-plasticity, non-linear mechanics, rheological fluid mechanics, hydroelasticity, thermoelasticity, numerical analysis, theory of relativity, cosmology, magneto hydrodynamics and high-temperature gasdynamics turned out to be a trend setting one for other IITs, RECs, other Technical Institutes and Universities that were in the formative stages. B.R. Seth's own researches on the study of Saint-Venamt's problem and transition theory to unify elastic-plastic behaviour of materials earned him the prestigious Euler's bronze medal of the Soviet Academy of Sciences in 1957. The other areas in which applied mathematicians contributed generously are biomechanics, CFD, chaotic dynamics, theory of turbulence, bifurcation analysis, porous media, magnetics fluids and mathematical physiology.



CHAPTER VIII

ASTRONOMY AND ASTROPHYSICS

Over the last half-a-century activity in astronomy has been most vigorous in all bands of the electromagnetic spectrum, from high energy gamma rays to the long wavelength radio waves, and indeed also the corpuscular radiations like cosmic rays and neutrinos adopted as probes to understand the exciting and fascinating phenomena in the macroscopic universe. These studies have resulted in a continuing train of spectacular discoveries, one following the other -- extragalactic radio sources, quasars, active galactic nuclei containing black holes, spinning neutron stars acting as pulsars, neutron stars and black holes in binary systems acting as intense X-ray sources, the universal microwave background at 2.73° K, dark matter, vacuum energy in the universe, bursts of energy in gamma rays of 10^{52} ergs!, emission of neutrinos by the sun, helioseismological observation of the internal constitution of the sun and so on.

This article represents an attempt to provide a brief overview of the efforts of Indian scientists during the last fifty years. The distinguished heritage on which these developments and contributions stand has been covered in many places, most accessibly in the Indian Journal of History of Science. A detailed presentation is far beyond the scope of this brief survey which by necessity has to be very selective.

COSMIC RAYS

Cosmic rays are high energy atomic nuclei and electrons raining on the earth from outside the solar system. They comprise mostly atomic nuclei from hydrogen to uranium with energies of ~10^7 eV

Himalayan Chandra Telescope on Mt. Saraswati in Hanle, Ladakh.



to 10^{20} eV or even more, with a spectrum describable more or less as a super position, or combination of a few power laws with indices of ~ – 2.7, –3.2, –2.8. The electrons constitute about 1% of the nucleonic component and their spectrum is known to extend from ~10^{7} eV to ~10^{12} eV, again describable as a power law which continuously steepens to an index of ~3.5 and is possibly cut-off at ~10^{13} eV. Even to this day, nearly a century after their discovery, we still do not understand precisely how and where cosmic rays are accelerated or what their origins are.

The work on cosmic rays in India was spearheaded by Homi J. Bhabha whose pioneering contributions are well known (see chapter on Torch Bearers). Mention must also be made of the important pioneering paper from D.M. Bose's School at Kolkata on the detection of particles with mass intermediate between the electron and puton using photographic plates.

Under Bhabha's leadership the Mumbai group was established at the Tata Institute of Fundamental Research (TIFR). The invitation to Bernard Peters to join TIFR provided important leadership to this programme. Some of the early results include: (1) establishing that all types of kaons, irrespective of the decay mode like t or q, appeared to have the same mass and could therefore be different decay modes of the same particle, (2) accurate determination of the life-time of the muon, (3) noting that kaon production was associated with hyperons, (4) measuring the intensity of the penetrating component of cosmic rays up to great depths ~10,000 metre water equivalent, and detecting for the first time the high energy neutrinos generated in the atmosphere by cosmic-ray interactions, (5) measurements of the composition and spectra of cosmic ray nuclei, (6) detecting the presence of high energy electrons in cosmic rays, (7) measuring the amount of radioactive nuclei generated by cosmic ray interactions with the earth's atmosphere, like ^{7}Be, ^{10}Be, ^{35}S and ^{33}P which acquired great importance in dating various geophysical and archaeological samples, (8) discovery of increased production of nucleon antinucleon pairs at high energies using extensive air showers, and (9) carrying out observations on the platform provided by the Space Lab-3 with a solid state track detector capable of recording both the time and direction of low energy cosmic rays which provided evidence that the very low energy 'anomalous' cosmic rays were neutral particles from interstellar space which enter the solar system, get ionized and accelerated to energies of about 10 MeV/nucleon.

Considerable theoretical effort was also put in to understand these experimental findings: relating to the composition of cosmic rays, where the abundance of lithium, beryllium and boron relative to those of carbon and oxygen are enhanced by a factor of almost a million compared to their 'universal' abundance. This is understood by assuming that cosmic rays are accelerated in the Galaxy, in numerous sources embedded in the galactic disc. It is assumed that primary cosmic rays are accelerated with a composition which follows the universal abundance with a slight enhancement by ~ 10 X of those elements with relatively low first ionization potentials. These primary cosmic rays diffuse out of the source region into the interstellar medium and then leave the Galaxy. During this diffusive transport both in the source regions and in the interstellar medium some of the nuclei undergo nuclear spallation reactions with the ambient matter and the spallation products fill up the deep holes in the universal elemental distribution, such as of the light elements. By noting that the mean density of the interstellar medium in the solar neighbourhood is about 0.1 – 0.2 hydrogen atom cm^{-3}, and that the spallation cross sections are ~ 50-100 mb, it would require a residence time of about 10 million years for the cosmic rays in the Galaxy.

This idea that cosmic rays diffusing slowly

through the Galaxy progressively becomes untenable as the energy of cosmic rays increases and at E ~10^{15} eV their gyroradii in the galactic magnetic fields of ~5 μG become comparable to the length scales of magnetic inhomogenities and the cosmic rays start leaking into the general intergalactic medium. Thus we expect that at extremely high energies beyond ~10^{18} eV the observed cosmic rays indeed originated in objects far beyond our own Galaxy. This idea of an extragalactic origin for the highest energy cosmic rays has interesting implications: Observations performed by Penzias and Wilson have shown that all space is filled with thermal background radiation leftover from the big bang origin of the universe, the present temperature being ~2.7°K. In the rest frame of a cosmic ray proton, at sufficiently high energies, say beyond ~10^{20} eV, the microwave background appears Lorentz boosted to energies above the threshold for pion production. Such interactions will take place with progressively increasing probability beyond 10^{20} eV, de-energizing the cosmic rays. It has been pointed out that the spectrum of cosmic rays could be cut-off rather sharply beyond 10^{20} eV, if they are truly extragalactic. Thus there is a strong suggestion that we have sources of highest energy cosmic rays nearer than ~ 10 Megaparsec (~3 x 10^{25} cm), a region containing very few active galaxies.

> LET ME SAY HERE AND NOW MY BELIEF THAT THERE IS NO SCIENCE SO GRAND, SO ELEVATING, SO INTENSELY INTERESTING AS ASTRONOMY.
>
> C.V. RAMAN

The electron component of the cosmic rays, because of the smallness of the electron mass, is even more sensitive to the radiation and magnetic fields in the interstellar medium. Initially it had been thought that there were no electrons in the primary cosmic radiation. Efforts were made by the TIFR group to detect electrons using photographic emulsion stacks. The first balloon flight for this in 1961, part of an Indo-US collaboration failed; in the meantime the electron compound was discovered by the Chicago group. Thereafter, further flights with emulsion stacks by the TIFR group were successful and pioneering work carried out that laid the foundations for our understanding of the higher energy electron compound. An electron of energy E when it scatters on a soft photon of energy $\in$, through the inverse-Compton process, it generates a gamma-ray with mean energy $E_r \sim (E^2/m_e^2 c^4)\in$. Similarly gyrating in a magnetic field of strength B it radiates synchrotron radiation around a frequency $\upsilon_8 \sim (E^2 eB/m_e^3c^5)$ giving rise to galactic radio emission. Both the facts that in these processes the electron loses part of its energy and that this energy is carried away by photons, have astrophysical significance. Since the energy loss increases quadratically with the energy of the electron, even an electron having almost infinite energy will slow down in a given time to a finite energy. Thus the fact that we do see electrons of E ~ 2500 GeV implies that the propagation time is very short or equivalently there are sources of cosmic rays as close as ~ 10^{20} cm (~ 30 pc); if this were the typical spacing on the galactic disk then there are about ~ 10^4 sources accelerating cosmic rays at least up to several thousand GeV. The observed spectrum of the electrons is a sum of the contributions of all the sources and by fitting the spectrum we conclude that the typical residence time of electrons as well is ~ 10 million years in the Galaxy, similar to the nuclear component of cosmic rays. The other implication pertaining to the energy carried away by the scattered photons leads to X-ray, g-ray and radio astronomies, and will be dealt with in later sections.

Gamma Ray Astronomy

High energy cosmic-ray particles, both nuclei and electrons when they interact with ambient matter, radiation and magnetic fields can generate gamma-rays. Thus, gamma-ray astronomy is expected to reveal astronomical objects where special conditions obtain for the acceleration of particles to high energies. The processes that lead to the production of gamma-rays in the astrophysical context are (1) nuclear excitation followed by deexcitation, (2) production of neutral pions (and η° etc) and their subsequent decay into gamma-rays, (3) bremstrahlung by high energy electrons, (4) inverse-Compton scattering, (5) particle-antiparticle annihilation, and (6) cyclotron line emission in intense magnetic fields, near neutron star surfaces. Astronomical observations over the last few decades have revealed large number of objects in which one or more of these processes generate gamma rays.

Except at very high energy, much of gamma ray astronomy is conducted either high up in the atmosphere with balloon borne instruments or outside the atmosphere altogether from 'space'. Ground based detectors are very effective in conducting astronomy at high energies beyond ~ 100 GeV. A gamma ray from an astronomical source, when incident on the top of the earth's atmosphere, generates an electromagnetic cascade of e^+, e^- and γ. These particles, and also the Cerenkov radiation and the fluorescence generated by these relativistic charged particles in the atmosphere can be observed at the ground level.

At the highest energies gamma ray astronomy is carried out from the ground using either an array of small parabolic telescopes with a photomultiplier at each of their foci measuring the arrival time of the wave front of Cerenkov photons or with large multi-mirror telescopes with an array of photomultipliers at the focus to image the Cerenkov emitting regions. The Indian effort in this area back to the 1970s and currently two major facilities are operating: a wavefront sensing array at Pachmarhi and TACTIC — array of 4 imaging telescopes deployed in Mt. Abu.

Most recently it has been noted that the threshold for observations of celestial gamma-rays using this technique can be lowered to about 20 GeV, when such Cerenkov telescopes are operated from high elevation ~ 4,500 m. Hanle at Ladakh with remarkably clear skies and low atmospheric extinction would be an ideal location for conducting ground based astronomy. With such an effort at Hanle, the energy range covered by the ground based observations will have a significant overlap with the energy range in which satellite borne instruments function, allowing complementary astronomical studies.

Gamma ray bursts (GRBs) are perhaps the most energetic and relativistic phenomena taking place in the universe; in these about 10^{52} ergs of energy is emitted as gamma rays in a narrow cone of opening angle ~ 10° within several tens of seconds (in our reference frame). When telescopes were pointed in these directions afterglows were also discovered in the optical bandwidth in several cases. Such studies also identified the galaxies which hosted such events and these were at redshifts of z ~ 1. Extensive study of afterglows have been conducted from the Indian Astronomical Observatory – Hanle, UP State Observatory – Naini Tal and Vainu Bappu Observatory – Kavalur.

X-ray Astronomy

In 1949, a rocket payload detected X-rays emitted by the sun and within a period of about five years the million degree solar corona and the solar flares were identified as strong emitters in the X-ray domain. The field of X-ray astronomy has since flourished with discovery that a remarkably large class of objects emit X-rays. Indian participation in this area and the astrophysical and cosmological interpretation have been both intense and extensive. The initial involvement started with theoretical studies and with observations in the hard X-ray band using balloon borne instruments. Soon such efforts were extended to include the soft X-ray band with instruments carried by rockets and satellites. Besides the localized sources men-

tioned above there exists a diffuse background of X-rays which is truly extragalactic and has an intensity exceeding that of the emissions from our own galaxy. Indian scientists also established fruitful collaborations with their colleagues from other countries. One of the important discoveries of X-ray astronomy is that condensed objects like black holes and neutron stars, accrete matter from a companion star with which they form a bound Keplerian system, and the accreted material which carries angular momentum with it forms a disk around the compact object, emits X-rays and subsequently falls onto the compact object. A partial list of some of the important results obtained through the participation of Indian astronomers and astrophysicists is given below:

1. Optical identification of the very first extra-solar system X-ray source Sco X-1
2. Measurement of the spectrum of the diffuse extragalactic background of hard X-rays and its interpretation as thermal bremstrahlung.
3. Discovery of flaring phenomena in X-ray emission in Cyg X-1 and rapid variability in the X-ray emission of BL-Lac objects.
4. X-ray survey of flare stars and the study of the correlation between X-ray luminosity and bolometric luminosity.
5. Pulsar X-ray emission.
6. AM-Her type soft X-ray sources.
7. Theoretical work on the effect of accretion torques on the spin-period of X-ray pulsators.
8. Detection of quasi periodic oscillations at ~ 100 ms in the superluminal black hole binary GRS 1915+105 using the instrument on the Indian satellite IRS-P3.
9. Evidence for the disappearance of matter into a black hole.
10. Indirect evidence for ionizing radiations in novae.

The Indian Space Research Organization is planning to launch in 2005 ASTROSAT, a satellite carrying a multi-telescope payload covering the electromagnetic spectrum in the hard X-rays, soft X-rays, ultraviolet and optical bands.

Ultraviolet Astronomy

Since the discovery of UV astronomy with rocket borne instruments more than 50 years ago the field has had an exciting growth with the advent of the space era. The Ultra Violet Imaging Telescope being developed by the Indian Institute of Astrophysics for launch aboard the ASTROSAT to be launched by the Indian Space Research Organization is very timely. It rides on the crest of developments in detector technology and is therefore expected to make several important discoveries, as has been the case in astronomy, whenever a new wavelength band is probed with unprecedented sensitivity and resolution.

Optical Astronomy

From the earliest times, there has been great interest in optical astronomy in India. Remarkably clear understanding of the spherical nature of the earth, moon, and the sun and inductively of all stellar bodies, and a phenomenal ability to calculate the movements of the planets had been achieved with astronomical observations carried out with the unaided human eye. There were the great masonry ground based observatories the *Jantar Mantars* of Maharaja Jai Singh of Jaipur that can still be seen as archaeological monuments. With the advent of telescopes 300 years ago in India came the discovery of the binary character of the bright star α-centauri. The period of ~ 250 years that intervenes between the birth of modern optical astronomy on the Indian soil and the beginning of the epoch covered here is filled with several equally remarkable discoveries, such as the discovery of the spectral lines of helium in the spectrum of the sun, an element unknown at that time.

The archives of the Kodaikanal Observatory contain about 50 years of spectroheliograms and white light pictures of the sun taken day after day. They are a treasure house for studying solar rotation and evolution of magnetic fields through the 11-year solar cycle.

Solar Astronomy

In the late 1950s, the study of the sun concentrated on the mapping in detail the intensity distribution in the umbrae and penumbrae of sunspots in relation to the brightness of the photosphere.

The solar tower telescope completed and installed at the Kodaikanal Observatory in 1960 with an f/90 objective provided a high resolution solar image. This was coupled with a high resolution spectrograph and served as a frontline research facility in the following three decades. Some of the important research programmes completed with this facility are: high resolution spectroscopic studies on the pattern of the out-flow of plasma in the penumbral filaments of sunspots known as the Evershed effect; detailed study of the temperature and local velocity fields in the temperature minimum region of the solar atmosphere using molecular lines as diagnostics, properties of the 5-minutes oscillations in the photosphere now known as the *p*-mode oscillations, mapping of the weak longitudinal magnetic fields with a Babcock type magnetograph constructed at Kodaikanal. A study of the spectroscopic profiles in the K-line of Ca-II (at λ 3933 Å) both of the very fine spatial structures on the sun (sun studied under high resolution) and of the unresolved sun (sun studied under low resolution, or sun as a star) showed that the two K-line profiles have identical line widths. This led to the discovery that these fine structures (now named as the bright fine mottles or bright points) which are ubiquitous are the agencies that collectively provide that K-line width in the sun as a star which enables the sun obey the line width-absolute magnitude relation (or the Wilson Bappu relation). Further study of the K-line emission from the plages (extended large scale structures representing active regions on the sun) led to the new finding that the sun viewed as a star in the light of the Ca-II K line appears as a variable over time in consonance with the 11 year solar-cycle. This opened up a new field of study namely the detection of stellar cycles by monitoring the stars in the K-line; such modulation was also used to measure the rotation rate of slowly rotating stars. The dynamical properties of the bright points in the solar chromosphere like evolution patterns, life times, amount of thermal flux they transport and so on have been studied in great detail.

Three major investigations using the unique collection of the synoptic observations on the sun at Kodaikanal commencing from the beginning of the 20th century and continuing to the present are: i) precise determination of the rate of rotation and differential rotation, ii) the dynamics of the large-scale unipolar regions on the sun that is intimately connected to the solar cycle mechanism which led to the discovery of the high latitude component of activity and the concept of the extended solar cycle; and iii) the variation of the size of the chromospheric network cells with 11-year solar cycle, which implies changes in the convection zone with the solar cycle. Data collected by the Indian team from the *Maitri* station in Antarctica during the local summer (when the sun can be observed almost round the clock) was used to determine the lifetime of these convective cells which turned out to be in the range of 22-24 hours.

The dome of the Solar Tunnel Telescope at Kodaikanal.



Study of the physics of the solar corona during total solar eclipse has a long list of achievements since the beginning of the 20th century by the Kodaikanal/IIA team. The discovery of the emission lines of the Balmer series, D^3 line of Helium, H and K lines of singly ionized calcium in the solar corona at the total solar eclipse of March 7, 1970, in Mexico, indicated the presence of cool columns of plasma embedded in the hot coronal surroundings. Another instance is the discovery of small period oscillations in the range of 5 sec to 90 sec in the corona using high precision photometry at the total solar eclipses of 24 October 1995 at Kalpi, Rajasthan, and at the eclipse of 26 February 1998 in Venezuela.



Decametric array of dipoles at ~ 35 MHz deployed in a 'T' configuration at Gauribidanur, near Bangalore.

During the last decade, the Udaipur Solar Observatory in the middle of the Pichola Lake, a unique scenic and scientific setting has been operating a telescope to record the p-mode oscillations on the sun -- as the one of the six stations forming a network around the earth known as the GONG (Global Oscillation Network Group) project by the National Solar Observatory, Tucson. This has brought out the presence of millions of acoustic modes present in the interior of the sun which could be used as diagnostics to study the physics of the solar interior. The rotation rate profiles in the interior of the sun, and possible changes in the p-mode frequencies with the solar cycle have been mapped using the valuable data. In addition, it has been confirmed that the thermodynamic parameters in the solar interior are more or less the same as have been assumed so far and so the source of discrepancy between the solar neutrino numbers observed and those expected has to be sought by reexamining our understanding of the physics of neutrinos.

Theoretical investigations covering the study of the dynamics of magnetic flux tubes in the photosphere under a variety of near realistic conditions have been carried out. The response of the magnetic flux tube to the buffetting by the granulation, tending to confine the magnetic flux into thin tubes, the excitation mechanism of oscillations in the magnetic network on the sun are some of the problems that have been investigated. The thin flux tubes threading the photosphere fan out in the chromosphere, and provide the channel for supporting magneto acoustic waves that heat the chromosphere. Using the extensive sunspot data as diagnostics, the global modes constituting the solar magnetic field pattern has been derived. On this basis, solar activity is interpreted as originating by the interference of the axisymmetric odd degree mode hydromagnetic oscillations. Extending this study, it has been shown that the odd degree modes (up to $l = 21$) can reproduce the observed magnetic fields at all latitudes on the solar surface and their migration characteristics. A theoretical model of the stability of the coronal loops has been developed on the basis of the existence of force-free magnetic fields in them.

The decameter array at Gauribidanur has been used to study the outer solar corona and has detected for the first time, rapidly propagating radio bursts. Time sequence studies of propagation of such bursts have been used to infer the physical conditions in the corona. Recently, this array has been upgraded by adding many dipole antennas, and a 1,024 channel digital correlator, to operate as a radioheliograph at fequencies < 150 MHz that can image the outer corona of the sun. An interesting

new finding is of a class of discrete radio emmitting source in the corona termed 'noise storm' that appears a few hours before the commencement of the Coronal Mass Ejection (CMEs) events, which are explosive phenomena in the corona. This provides an effective means of predicting the CMEs.

Considerable work was done by Bappu, and his associates, in the study of the physics of the coma and tail of comets, Spectroscopic, photometric and polarization studies of comets. Arend-Rolland, Mrkos, Ikeya-seki and West, have yielded a wealth of information both on the molecular species and the properties of dust in the coma and tail. Comet Halley was observed with concentrated efforts using the Kavalur, Rangapur, Nainital and Mt. Abu telescopes. Spectroscopic observations from Kavalur at high resolution mapped the abundance of the molecular species (C^2, CN, CH, NH) at various locations within the coma. Spectropolarimetric studies of silicate rich coma of Comet Hale-Bopp and Comet Wild 2 have been used to derive the size distribution, porosity and silicate to organic ratio of grains. Theoretical investigations on the spectroscopic state of the C^2 molecule in the coma of comets have explained satisfactorily the intensity distribution in the Swan bands of C^2 and in other molecular species.

One of the most important discoveries of twentieth century solar system astrophysics is the discovery of the rings of Uranus by Indian scientists using the 1-m telescope and fast photoelectric recording system.

Stellar, Galactic and Extragalactic Astronomies

Despite the strong recommendations of Saha, Raman and others, the growth in India of optical astronomy of the distant stars and galaxies was rather slow. It is not the lack of talent and interest in this field that was responsible for this but the high cost of the modern large optical telescopes; and the skies clouded by the monsoons over a good part of the year, also posed great difficulties. Nevertheless, the interest was strong and it was kept alive by a group of dedicated astronomers, notably M.K.V. Bappu who was elected President of the International Astronomical Union in 1979. To the Nizamia Observatory which had been operating since 1901 near Hyderabad, three new observatories were added at Varanasi (1954), Naini Tal (~1955) and Kavalur (1967). The latter two acquired 1 m optical telescopes in 1972. Using the technique of stellar occultations, astronomers of the Indian Institute of Astrophysics (IIA) discovered the Rings of Uranus (1977) and the Outer Rings of Saturn (1984).

The development of optical astronomy in recent decades proceeded along multiple paths: a) fabricating and commissioning of Telescopes of larger aperture such as the Vainu Bappu Telescope (A=2.34 m, set-up at Kavalur ca 1987) and the Guru Shikar, Near Infrared Telescope (A≈1.22 m at Mt. Abu, ca 1992), (b) making guest observations from a wide variety of astronomical facilities across the world like those at Mauna Kea, La Palma, Le Paranal in the Chilean Andes, and the Hubble Space Telescope operating in space beyond the vagaries of weather and climate; and most recently, (c) discovering and developing a superlative astronomical site within India itself.

These concerted efforts have resulted in a large body of excellent astronomical research in almost all branches of optical and near infrared astronomy -- star formation, stellar evolution, including the observations of crucial phases of the formation of planetary nebula, and of a star on its way to becoming a white dwarf in an apparent reversal of evolution turning into a yellow supergiant, observations of the light curves and spectra of novae and supernovae, study of variable stars, HII regions, extragalactic astronomy with observations of variability of the luminosity of the nuclei of active galaxies indicating the presence of black holes, gravitational lensing, and optical observations as complementary to those carried out in other wavelength bands such as X-rays, gamma-rays and radio waves.

The recent identification and development of a superlative site for astronomy in India deserves special mention, as this would provide opportunities for future



The 2.3 m Vainu Bappu Telescope at Vainu Bappu Observatory, Kavalur, Tamil Nadu.

A special feature of this telescope is that its operations, and indeed of the five focal plane instruments can all be controlled from Hosakote, near Bangalore, using a dedicated communication link via transponders on board Indian satellites. Astronomical observations are routinely underway in this remote mode and the Observatory was declared open to general astronomical use on 29 August 2001. A Binocular Telescope with two mirrors each of 6.5-m aperture has been proposed for installation on Mt. Saraswati with international participation within the current decade. Because of the extremely cold nights, $T_{min} \sim -30°C$, and very low column density of precipitable water vapour above the site, this has been proclaimed as the best location in the world for carrying out ground based astronomy in the near infrared. Most recently it has been shown that this site is excellent for ground based gamma-ray astronomy with Cerenkov telescopes.

developments on a scale and of quality hitherto not available, not only to astronomers within India but also those working all over the world. This site, Mt. Saraswati (longitude 78° 57′ 51″E, latitude 32° 46′ 46″N) in Hanle, Ladakh (as indeed the Indian subcontinent), lies plumb in the middle of a large lacuna in such facilities, extending almost half the globe from the Anglo Australian Telescope in Siding Springs $l \approx 160°$ E and the European facilities at La Palma in the Canary Islands $l \approx 27°$W. Thus, for the observation of variable sources, the facilities at Hanle will play a crucial role, allowing observations to be carried out at night when it is day elsewhere. Some of the characteristics of the site which make Hanle most suitable for further instrumentation and development are presented in the Table.

Site Characteristics of Mt. Saraswati

Accessibility	**around the year**
Number of spectroscopic nights	260 per year
Number of photometric nights	190 per year
Precipitable water vapour	$\leq$ 2 mm
Annual precipitation of rain and snow	< 7 cm
Extinction in V band	~ 0.1 mag/air mass
Sky brightness	μ_V = 21.5 mag/arcsec^2
Median seeing	0.8 arcsec
Distribution of useful nights	uniform round the year
Median temperature	-2° C at night (minimum –24°)
Median relative humidity	30% at night (minimum < 10%)
Median windspeed	2.2 m/s (8 kmph) at night
Wind direction	Prevailing south-south-westerly

Beginning of A New Era

At the midnight hour intervening 26/27 September 2000, the first astronomical light was imaged through an optical/infrared telescope from Mt. Saraswati, heralding the birth of the Indian Astronomical Observatory.

Ground based and Balloon Borne IR and mm Wave Astronomies

These wavelength bands bridge the gap between the optical and the radio, and here the transparency of the earth's atmosphere is only partial. Consequently, it is necessary to move to high mountain altitudes of 4,000 m or more for near infrared studies, and to even greater heights of 30-40 km into the stratosphere with balloons for conducting astronomical observations in the far infrared.

Ground based infrared astronomy in India was pioneered by the Physical Research Laboratory, Ahmedabad, and the balloon-borne effort has been the forte of the Tata Institute of Fundamental Research. In this wavelength band one can probe cores of molecular clouds, study the star forming regions and HII regions, study the circumstellar dust heated by the shorter wavelength stellar radiations, and measure the planetary albedo. The measurement of the far infrared brightness temperature of Saturn's rings in 1982 was one of the major success stories of balloon-borne infrared astronomy in India. Currently telescopes of ~ 1 m aperture are being flown on balloons from Hyderabad, with sophisticated focal plane instruments cooled to liquid helium temperatures, like for example a Fabry-Perot spectrometer recently developed for collaborative studies with astronomers from ISAS in Japan.

The balloon flight facility at Hyderabad is an indigenous capability developed by TIFR. Flights with balloons of up to 10 m cu ft capacity, level flights at ceiling altitudes of 120.000 ft and payloads of 1 ton characterize this capability. It has been available to scientists from all over the world on a regular basis.

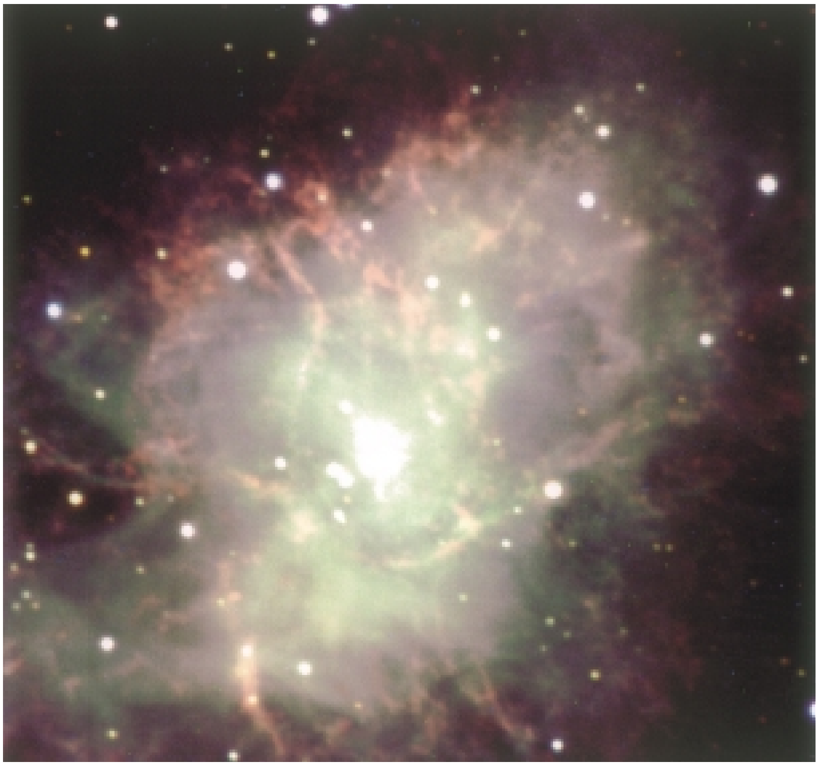
The study of molecular lines in the astrophysical context is one of the most important objectives of millimetre-wave astronomy. In an unprecedented technological effort in India, the Raman Research Institute built in-house a 10.4 m dish and installed it in their campus in Bangalore with a cryogenic Shottky mixer receiver at its cassegrain focus operated with dual polarization over the w-band, (tunable in the range 80-115 GHz)

Astronomy in Radio Waves

Radio astronomy began in 1929 when Karl Jansky discovered that radio waves are being emitted by our Galaxy in the form of radio noise. Over the last few decades, many remarkable discoveries have been made by radio astronomers which has revolutionized our understanding of the universe. The discovery of microwave background radiation has provided strong support to the Big Bang Model. Over 100 molecules have been found in the interstallar space; this lends support to the view that living forms may be have developed elsewhere and may be more widely prevalent than known.

One of the crucial problems in astronomy is to measure the angular diameter of stars and therefrom derive the physical diameters, whose knowledge forms an essential input to our understanding stellar

Crab Nebula imaged through the 2 m Chandra Telescope at Indian Astronomical Observatory.



evolution and radiation. Hanbury Brown and Twiss had realized that an interferometer could be built on the principle that if the light at two separated points is partially coherent, then the fluctuations in intensity at these two points are also correlated. In a remarkable effort, an Indian radio astronomer working with Hanbary Brown and Jennison demonstrated the feasibility of the idea by measuring the angular diameters of two bright radio sources in Cygnus and Cassiopeia in the year 1952. In the same year, radio observations of the sun were also commenced from Kodaikanal. Indian Scientists participated in the early phase-correlated interferometry in radioastronomy using the 21 cm line radiation from galactic neutral hydrogen, an interferometry conceptually more straightforward than intensity-interferometry, but in practice having much greater applicability. Pulsating radio sources (pulsars), which get born when the nuclear fuel of starts get exhausted, have provided a wealth of new information, including tests of the General Theory of Relativity. Pulsars were discovered by Hewish and Jocelyn Bell in 1968, through radio astronomical techniques at Cambridge, England. Within months of the discovery Indian investigations to improving the accuracy of the determination of the pulsar period, came in soon, followed up with a determination of the swing of the polarization axis within the duration of the pulse. There were pioneering efforts in measuring the polarization in radio waves, which resulted in the important discovery of the vector within the radiopulse of a 'Pulsar' serving at the same angular frequency as the pulse-train, immediately indicating that it is the 'rotation' of a neutron star that is responsible for the periodicity of the pulses and not radial oscillations with a pulse period of ~ 1 second. At that time, the underlying cause of this periodicity was not known, through it was speculated as either due to the rotation of a neutron star or due to the pulsations of a white dwarf. Continuing efforts led to the discovery of the glitch phenomenon in the Vela-pulsar, whereby the solid crust of the neutron star stressed during the slowing down of the pulsar cracks and settles down to a state of lower moment of inertia with a sharp increase in the rotational frequency. These and related studies gave birth to the 'polar-cap' model for pulsar emissions, according to which the observed pulses are due to 'curvature radiation' of relativistic electrons streaming along the curved magnetic lines of force, whose tangents periodically point in the direction of the observer as the neutron star spins. Even today this model provides the basic paradigm for pulsar studies.



10.4 m dish at Raman Research Institute campus, Bangalore.

A leading team of astrophysicists at the Raman Research Institute conceived, in the case of the binary X-ray sources of the possibility of recycled pulsars in binary stellar system wherein a neutron star could be spun-up by torques carried by accreted material. And, weaker the magnetic field, faster is the limiting rotational frequency, so that neutron stars with fields of ~ 108 Gauss could acquire periods of a few milliseconds! A year had hardly lapsed after this theoretical prediction, when a group at the California Institute of Technology in a

tour de force of radio astronomical techniques indeed discovered the first millisecond pulsar.

Over the last three decades several powerful radio telescopes have been designed and fabricated entirely in India, and these along with many outstanding scientific contributions, have placed India at the forefront of radio astronomy internationally. These telescopes have not only yielded results in the field of radio astronomy but have also contributed significantly to the growth of a major antenna industry in India and the construction of many satellite earth stations, troposcatter antennas etc. Notable among these telescopes are the Ooty Radio telescope (ORT), the Gauribidanur Tee Array, the Mauritius Radio Telescope and the recently constructed Giant Metrewave Radio Telescope (GMRT) near Pune, the world's largest radio telescope.

A radio astronomy group was formed at TIFR, Mumbai in 1963. The successful setting up and operation of ORT and GMRT are a result of the dedicated work of a large number of scientists, engineers and other staff of the National Centre for Radio Astrophysics, TIFR. The low man-made background in the 50-500 MHz band on the Indian subcontinent has allowed relatively simple radio telescopes to function at a high level of sensitivity. The low radio background was also the primary motivation for building the Giant Metrewave Radio Telescope at Khodad near Pune.

The ORT consists of a 530 m long and 30 m wide parabolic cylinder. The unique feature of the telescope set up in 1970 is that its long axis of rotation has been made parallel to that of the earth, by placing it along a hill with a natural slope of 11 degrees, the same as the latitude of Ooty. This allows tracking of a source in east-west direction by mechanical rotation. A phased array placed along the 530 m long focal line consiting of 1,056 dipoles allows pointing in the north-south direction.

During the 1970s, ORT provided arcsec resolution for about one thousand weak radio sources for the first time in radio astronomy by utilizing the method of lunar occulation. It was shown that not only was the comoving number density of the sources higher at earlier cosmic epochs, but also that their linear sizes were smaller. The results provided independent support to the Big Bang Model.

The Ooty Radio Telescope has been used extensively for studies of radio galaxies, quasars, supernova remnants, pulsars and interstellar and interplanetary mediums. Searches have also been made for Deuterium abundance in our Galaxy and for HI proto-clusters at a redshift of about 3.4.

The GMRT operates in the frequency range of about 38 Mhz to 1430 Mhz and consists of thirty parabolic dish antenna, each 45 m in diameter, forming a novel design. Of these antenna 12 are located in a central array of about 1 km x 1 km in area and the remaining 18 are placed along three 14-km long Y shaped arms. Feeds are at 50, 153, 233,327,610 and 1420 MHz. State of art electronics has been built

The 530 m-long Ooty Radio Telescope (ORT).





Several of the 45 m diameter parabolic dishes of the GMRT Central Array.

for the GMRT. Signals received by each of the 30 antennas are brought to a central receiver room on optical fibre links, Fourier transformed and cross multiplied. The GMRT operates as an earth's rotation synthesis telescope and provides arcsec resolution and extremely high sensitivity.

The GMRT has been in operation over the last two years. Several objects in our Galaxy have been studied in detail. Nine new supernova remnants have been identified. HI regions, the birthplace of stars, are being studied for determining their electron temperature. The Galactic Centre region is being mapped in detail. Observations have been made of absorption of radio waves from distant radio sources by cold hydrogen gas in our Galaxy. Studies of recombination lines are also being made. Multi-wavelength observations of pulsating radio sources have given clues about their emission mechanisms.

Observations have been made of nearby galaxies, cluster of galaxies,relic radio sources and giant radio galaxies and quasars. High sensitivity GMRT observations of several low redshift Damped Lyman alpha systems, based on absorption of radio waves from distant quasars by cold and warm hydrogen gas (HI) have indicated that they are associated with Dwarf galaxies. Searches for HI absorption associated with radio galaxies and quasars have also been made.

Other Radio Telescopes: The Gauribidanur Tee Array consiting of 1,000 dipoles at 34.5 Mhz placed along 1.5 km E-W and 0.5 km N-S was built near Bangalore by the Raman Resarch Institute and the IIA during the 1980s. It has been used for studies of many objects in our Galaxy, and particularly for a large scale survey of the Radio Sky at 34.5 Mhz. Recently IIA has built a 1.3 km E-W x 0.44 km N-S Radio Heliograph for mapping the sun in the range 40-150 MHz. In collaboration with the University of Mauritius, the above groups have also built a Tee Array with 1,024 helical antennas placed along a 2-km long E-warm and 4 Nos. of movable trolleys with 32 helices along a 0.5 km N-S arm. The Mauritius Radio Telescope has mapped the radio Sky at 150 MHz. The Raman Research Institute has also constructed a millimetre wave telescope with a precision 10.4 m single. It has parabolic dish antenna for observation of molecular gas in our Galaxy. The Physical Research Laboratory at

Ahmedabad has also built a large dipole array for multi-station observations of interplanetary scintillation at about 103 Mhz but only one of the stations is in operation at present; the triangle with a typical baseline of 200 km around Ahmedabad has apertures of 20,000 m^2, 5000 m^2 and 5000 m^2. Besides observing with these facilities developed by them, the Indian radio astronomers also use extensively the facilities in other countries, like the VLA in America. With access to such facilities extensive research is being carried out in almost all branches of radio astronomy.

India offers several advantages for radio astronomical research. Its close location to the geographic equator allows a large coverage of both the northern and southern skies. Indian scientists have also taken advantage of the relatively low level of radio frequency interference in their country. Also, the metrewave radio telescopes are labour extensive.

Over the last thirty years, modern astronomy has taken deep roots in India. In particular, the GMRT is likely to open up many discoveries and offers challenging opportunity for engineers and scientists, not only from India but also to those from developing countries and from across the world, to use its facilities.

Theoretical Studies in Astrophysics & Cosmology

Gravitation and Cosmology: The contribution to the theoretical studies in astronomy started with the brilliant work by Meghnad Saha around 1920. He derived the famous 'Saha-equation' which described accurately the state of ionization of various atoms in a gas at a given pressure and temperature, an equation which led to the spectral classification of stars. This was followed a little over 10 years later by the work of S. Chandrasekhar i.e. electron degeneracy in white-dwarfs which had the important consequence that their masses could not be more than ~ 1.4 $M_{\odot}$, lest they gravitationally collapse into black holes. D.S. Kothari and his colleagues investigated the properties of degenerate matter in the cores of stars deriving various transport coefficients. In the post-war period leadership was provided by V.V.Narlikar at Varanasi and N.R. Sen in Kolkata. Important contributions to the field of General Relativity and Cosmology respectively related to the Vaidya metric for a radiating spherical star and the Raychoudhuri equation describing a universe with rotation and shear. A result of considerable beauty and importance is the formulation of Fermats principle in General Relativity,



The metre-wave radio telescope at Bras D' ean, North-East Mauritius.

with applications to the theory of gravitational lensing and to other problems. Detection of gravitational waves emitted by a coalescing binary of a pair of neutron stars or a black hole neutron star combination, amidst the background noise of a variety of vibrations is veritably the search for a needle in a haystack.

Cosmology has held a great fascination for Indian scientists, and important contributions have been made towards understanding the formation of large-scale structures like galaxies and clusters of galaxies in the universe, the anisotropies in the

primordial microwave background, gravitational lensing and shear, quantum cosmology, topological defects like superstrings and monopoles, inflation and dark matter, and of course the debate on various theories for the origin of the universe. Thirty years ago came the important suggestion that this material is non-baryonic e.g. not normal matter; but that it comprises elementary particles which have only weak interactions. This suggestion has been the paradigm for extensive studies of dark matter with a large class of known and hypothetical elementary particles, discussed as possible candidates. The existence of such particles of dark matter is essential not only for the formation of the galaxies but for understanding the anisotropy of the microwave background.

Theoretical Astrophysics: In the area of Theoretical Astrophysics we highlight only those studies that have not been alluded to in our phenomenological descriptions earlier:

To begin with, extensive studies on the theoretical aspects of cosmic rays were carried out. The production of nuclei by spallation in the earth's atmosphere was calculated with particular emphasis on radioactive nuclei which may serve well for archaeological and geophysical dating. The same spallation processes taking place in the interstellar regions produce the rare nuclei Li, Be, B etc. In order to understand the spectrum of the low energy part of the heavier primary cosmic rays like C, O, Si and Fe, which become flat because of energy lost in ionization of the interstellar medium, and simultaneously generate the right amount of secondaries like Li, Be, Be, etc. the leaky box and nested leaky box models were developed. Such models were also used to study the propagation of electron-component of cosmic rays in the Galaxy where one has to include the energy loss suffered by the electrons through synchrotron radiation in the galactic magnetic fields and Compton scattering on starlight and the universal primordial microwave background. Such considerations indicated that the cosmic rays electrons are accelerated to energies of $\sim 10^7 - 10^{13}$ eV in about 10^4 sources sprinkled across the galactic disk.

As the cosmic rays propagate through the earth's atmosphere they interact to generate unstable particles like pions and kaons whose decay produces neutrinos. Apart from making the first detailed calculation on the flux of such neutrinos and the flux of muons expected through their interactions inside the earth, Indian scientists also observed for the first time anywhere, in experiments deployed deep underground in the Kolar Gold fields the interactions of these neutrinos producing muons. Such experiments later carried out by the Japanese scientists at Kamiokande have indicated that the flux of the neutrino induced muons fell short of the theoretical expectation. Detailed analysis of the angular dependence of this depletion indicates that muon neutrinos 'oscillate' away into neutrinos of a different 'flavour' one that does not produce muons. This in turn implies that the muon neutrinos have mass ≥ 0.07 eV and would constitute a gravitationally significant component of our universe.

Indian scientists have worked on the torquing of the neutron stars by the accreted material in X-ray binaries and an application of these ideas to predict the possible existence of rapidly spinning recycled pulsars. Detailed work on the accretion processes, like the advection dominated accretion flows, theory of black hole accretion, and the work on the energizing of quasithermal particles and radiation in accretion flows with quasi-stationary shocks probe various aspects of this rich field. The use of the 'quasi periodic X-ray sources' to choose among the many possible equations of state of nuclear matter in a neutron star and probing the constitution of the neutron star core by studying the pulse profiles of pulsars are also noteworthy.

Supernova explosions, which represent the final gravitational collapse of a star which has exhausted its nuclear fuel, release $\sim 10^{53}$ ergs, mostly in the form of neutrinos. The detection of such neutrinos from the supernova SN 1987 A, which occurred in the large Magellanic Cloud, in deep underground detectors

not only confirmed the astrophysical theories of stellar evolution and collapse but also allowed bounds, to be placed by 'time of flight' arguments on the masses of neutrinos. The neutrinos also impart part of their momentum to the stellar mass surrounding the core and the debris of the explosion with a mass of several solar masses ($1M_O \sim 2X20^{33}$ g) which ploughs into the surrounding interstellar medium with velocities of several thousand km s^{-1}. Such debris and often the whole nearly spherical volume excavated by it emit radiations from radio to high energy gamma rays. Occasionally a pulsar is left behind at the centre of such a remnant which fills the remnant with high energy electrons. Such remnants are called 'plerions', as distinguished from shell-like supernova remnants where the observed radiation is seen to emanate from a shell. Significant additions to the theoretical knowledge of these phenomena have been made by Indian astrophysicists, including the understanding of shock-induced star formation.

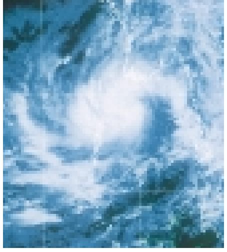
A series of investigations on the role of nonlinear plasma processes have shown that estimated Raman and Compton scattering processes and parametric decay instabilities are important in the generation, absorption and modulation of the non-thermal continuum of active galactic nuclei and related objects. The success of this model is demonstrated by the impressive way the entire spectrum of the quasar 3C 273 has been reproduced by the scattering processes mentioned above.

During the last decade the isolation of presolar grains of diamonds, rubies and other highly refractory substances has become possible from premature meteorites. Isotopic analysis of the elements like C and O in these grains show diversity by a factor of hundred or more, with respect to the bulk material in the solar system which is remarkably uniform. Studies indicate that these grains are formed in the atmospheres of different stars and thus carry the isotopic signatures specific to their nucleosynthetic histories and dredge up processes taking place in these stars. These isotopic signatures are preserved in a positive condition in the interstellar clouds, which were seeded by the stellar winds before the formation of the solar system. Several results of cosmological and astrophysical importance have emerged from a study of these isotopic anomalies including an estimate for the age of the universe as ~ 14 giga years.

There have also been important contributions to image reconstruction techniques in astronomy. In all of the above there has been significant involvement of Indian scientists

SCIENTIFIC COLLABORATION BETWEEN INDIA AND BRAZIL

Indian scientists and engineers are providing significant help to Brazilian scientists of the Instituto Nacional de Pesqquisas, Sao Paulo, for building a radio telescope near Paulo Cauchista in Brazil, called the Brazilian Decimetric Array (BDA). BDA consists of 30 antennas of 4-m diameter for studies of radio emission from sun and galactic and extra-galactic radio sources. In addition to exchange of experts, some of the critical parts of BDA are being built in India for BDA. This project is a good example of international collaboration in the field of basic sciences as a result of initiatives of individual scientists in the developing countries.



CHAPTER IX

PHYSICS

India has more than a century old tradition of creating and contributing to physics at the highest level, with a very wide base today of institutions, skills, knowledge and research activity. In this brief overview, we try to convey a sense of this experience. We then set the stage by recalling the unique pre-Independence (1947) contributions to physics. Some of the highlights of physics research in India in the following half century are then mentioned, in two parts; the period till roughly about a decade ago, and the last ten years.

The emphasis of India's comprehensive intellectual culture was broadly linguistic, philosophical and literary. However, thinking about the physical world, inventing mathematical ideas and languages, and experimentation and technology, all have ancient roots. One example of each of the above may be mentioned because, consciously or not, this is one of the formative influences of contemporary Indian activity in physics. The atomic theory was hypothesized by Kanada (6th century BC) who, along with Prasastapada, was the founder of the philosophical school called *Nyaya Vaiseshika* or Logical Atomism. Their argument for the particulate nature of matter was the manifest inequality of different bits of it; if matter were infinitely divisible, how could a mustard seed be unequal to the Meru Mountain ? The philosophers of this school went on to describe diatomic and triatomic molecules formed of elementary atoms, thermal dissociation of molecules, and shape and size of atoms. The Kerala School of mathematicians, starting with Madhava in the 14th century, discovered and used differential and integral calculus in the course of expressing trignometric functions as an infinite power series, obtaining the famous series of Gregory, Newton and Leibniz and thence a value of π accurate to 11 decimals, all this two to three centuries before calculus was invented in the West, in a different context, by Newton and Leibniz. The fertile coming together of these three kinds of activity, a hallmark of contemporary science, did not happen and it was with the British conquest of India that science as we know it today entered the country. Western higher education began to be officially sponsored and supported from the early 19th century. Towards the end of the 19th century and the beginning of the 20th, three factors, namely the results of this policy, resurgent national as well as cultural consciousness, and the revolution in physics came together to create the most remarkable period in modern Indian science. The best known figures of this period are icons in the contemporary national imagination; together they gave India a special position in the physics world. Their work and influence are briefly mentioned here, both for their own interest and because this is the immediate background for physics in India.

The first, and in many ways the most unusual was Jagadis Chandra Bose (1858-1937), a pioneer in experimental studies of ultra-short (millimetre wavelength) electromagnetic waves, and in the physical response of plants to stimuli. He went to study medicine in London in 1880, shifted to science at Cambridge and returned to teach at Presidency College, Kolkata. Here, in the 1890's he started



A typical flower texture exhibited by a columnar liquid crystal. This mesophase was discovered in compounds made of disc-shaped molecules in the Raman Research Institute in 1977.

experiments on microwaves, generating and detecting them over distances of the order of a mile, a year or more before Marconi's experiments on longer wavelength radio waves. He established their identity as transverse electromagnetic waves with ingenious but materially simple table top experiments, taking advantage of their millimetre wavelength. The horn antennae, waveguides, and the semiconductor rectifiers he developed for detection prefigured the detailed exploration of microwaves and the knowing use of pn junction (silicon) rectifiers by half a century. In the early years of the 20th century, J.C. Bose began studying electrical and mechanical response of plants to stress, by devising techniques for amplifying extremely minute movements and changes. Clearly it was far too early to make scientific sense of the striking results, and their often anthropomorphic description in a literal minded scientific age did not help. This scientific explorer was also a great teacher, emphasizing demonstration and experiment.

Somewhat later came C. V. Raman (1888-1970), the greatest of Indian scientists. Precocious (his first scientific paper was published when he was about seventeen), indigenous and entirely self taught, he was the natural scientist of the world of light and sound waves. The first half of his career (1907-1933) was spent in Kolkata and the remainder in Bangalore. He is best known for his discovery (Raman effect, 1928) that photons interacting with matter can change their frequency, the shift being characteristic of its internal excitations. Prior to this, photons were known to be fully absorbed (e.g. photoelectric effect) or scattered elastically (ordinary or Raleigh scattering of light, or Compton effect); these are first order processes. The Raman effect, second order in the photon field, is a new phenomenon probing the internal states of molecules and of condensed matter. Some of the other major discoveries of Raman are the origin of the musical nature of the drums *tabla* and *mridangam*, diffraction of light from stationary wavefronts created by ultrasound in liquids, light scattering from polymers and from short-lived shear fluctuations in fluids, and the soft mode associated with structural phase transitions in solids. Raman's style was imaginative and incisive, doing relatively simple but often ingenious experiments to probe

phenomena. He was primarily a research scientist with a large number of research students over a long (~ 40 years long) and productive scientific career; these students helped shape physics in India for a generation or more.

Satyendranath Bose (1894-1974) was the first to realize the statistical mechanical consequences of identity in quantum particles (Bose-Einstein statistics) and applied it to light or photons, thus inventing quantum statistical mechanics. Meghnad Saha (1893-1956) showed that the origin of unusual stellar line spectra is the presence of different ionic species in stellar matter due to thermal removal of different numbers of electrons from radiating atoms, thus clarifying a great mystery in astrophysics and providing a way of estimating temperatures of stars. Saha was also active in public life, e.g., science and economic planning, calendar reform, a stint as nominated Member of Parliament, and founding and nurturing an Institute of Nuclear Physics in Kolkata. K.S.Krishnan (1898-1961) collaborated in the discovery of the Raman effect, did very precise measurements of magnetic anisotropy in crystals and understood the results in terms of crystal fields, and also proposed a theory for the resistivity of liquid metals based on the scattering of free electrons by a dense highly correlated collection of atoms. The theoretical astrophysicist S. Chandrasekhar (1910-1995; Nobel Prize, 1963) started his epic career from India where he had begun to think at the age of twenty or so about the maximum mass a stable star can have, the Chandrasekhar limit; he went on to develop this and other areas of astrophysics and cosmology on a monumental basis in England and then USA where he settled. These physicists worked mostly at universities, those being the only places for higher education and research in the pre-Independence period except for two primarily research institutions, namely the Indian Association for the Cultivation of Science, Kolkata, and the Indian Institute of Science, Bangalore.

In the 1950s, the picture changed in several ways. The charismatic Prime Minister of independent India, Jawaharlal Nehru, believed strongly in nation building through centralized planning and government institutions, and in the essentiality of science both basic and applied for this. As a result, a large number of state supported research and development laboratories were set up, for example the cluster associated with the Council of Scientific and Industrial Research. This was also the period when 'big science' physics began to become prominent all over the world following the release of nuclear energy, and the atom bomb. The field found a visionary leader in Homi Bhabha, (1909-1966) an outstanding theoretical physicist who was also very close to Nehru, well known for his work on 'showers' of electrons and positrons accompanying high energy cosmic rays as they pass through the atmosphere. Bhabha conceived and helped set up a collection of institutions such as the Tata Institute of Fundamental Research (TIFR, 1945) and the DAE (incorporated as Atomic Energy Commission in 1948) which itself had a wide spectrum of activities ranging from power reactors to metallurgy of nuclear fuel materials. He inculcated the spirit of self-sufficiency in instrumentation and technology development. He also built up people and groups, by choosing well, giving them the freedom and support needed, and generating and sustaining a spirit of great things to be done.

In physics, a number of groups quickly attained international prominence (in the 1950s and early 1960s) in relatively new fields, e.g., cosmic ray research, neutron scattering and radio astronomy. In the field of cosmic rays, D.M. Bose and others from Kolkata had observed very early (in 1941) cosmic ray particle tracks in photographic plates exposed in the Himalaya, and had identified new particles with a mean mass 200 times that of the electron. This was six years before Powell's systematic development of the photographic emulsion method, and discovery of pi mesons in cosmic rays. In TIFR, the cosmic ray



Balloon flights for study of cosmic rays.
(Inset): Bhabha releasing a balloon.

group used balloon flights carrying nuclear emulsion stacks to obtain important results on masses and decay modes of heavy unstable particles (produced by cosmic rays). This group established itself over the years as a major group in the study of primary cosmic radiation, particularly the heavy primary and high energy electron components. The extensive air shower array at Ooty was one of the leading facilities for the exploration of extremely high energy cosmic rays. The various depths available in the Kolar Gold Fields (KGF), up to almost 2 miles below the surface offered one of the few world class places for the study of extremely energetic cosmic ray mu mesons and neutrinos. Experiments at KGF were carried out on an international basis with groups from England and Japan; the collaborative effort with the Japanese group lasting over three decades must surely be one of the longest collaborative scientific efforts in the world. The KGF work resulted in the most comprehensive depth-intensity data for muons up to the greatest depth of 9,600 ft. below the ground. The first natural (atmospheric) neutrino interactions were detected in KGF in 1965. The first dedicated experiment to search for nucleon decay to a life time of up to 1,031 years was carried out at KGF; this was the first such detector operational in the 100 ton category. In neutron scattering, the group at BARC was one of the early leaders (in the 1960s) in using inelastic scattering to probe elementary excitations in condensed matter. The occultation radio telescope at Ooty, set up in 1970, provided important results relating to the apparent angular size of galaxies with their energy flux. The development of optical telescope facilities also dates to this period; a number of interesting results such as the discovery of rings surrounding Uranus, and the measurement of star clusters in the Large Magellanic Cloud and their kinematics are from this period.

Somewhat later, a number of 'small' or laboratory-scale activities, mainly in condensed matter physics, centered around individuals, began to bear fruit. Perhaps the best known is the sustained work on liquid crystals done at Raman Research Institute in Bangalore; the discovery of a new arrangement in liquid crystals, the discotic phase with a stacking of disc like molecules, (in 1978) is perhaps a high point in the contributions by this group, which

continues to be one of the leaders in the world in this field rich in new science and technology. A group in TIFR has, for more than a generation, made often pioneering discoveries in the still lively and fascinating field of rare earth intermetallic compounds. Their forte is synthesis and experimental analysis of anomalous systems in which the generally completely atomic f electrons (of the rare earth elements) hybridize with the *s* and *p* band electrons, to produce 'heavy electron' metals and insulators (the nearly localized electron moves slowly from site to site), or give rise to novel superconductors with unlikely ingredients (the rare earth borocarbides). In the field of quasicrystals, significant early contributions on different families, on structure, and on systematics of approximants are due largely to the Indian community of physical metallurgists. This was in a sense an offshoot of a major programme on rapidly quenched metals. Interesting studies on critical phenomena, e.g. breakdown of the rectilinear diameter law near T_C, and precise measurements of unusual exponents and critical light scattering near special critical points in carefully chosen fluid mixtures, date from this period, and are continuing. Following the Raman tradition, a number of soft modes in ferroelectrics were studied by optical as well as neutron scattering methods. High pressure studies of phases and phase transitions in metals and alloys have yielded insight into electron phases.

The tradition of atmospheric studies goes to back to S.K. Mitra at Kolkata in the thirties, and continued with important work on low frequency propagation in the ionosphere, aeronomy and the ozone problem.

We now describe Indian contributions to theoretical physics from the 1950s till the 1980s. In the 1950s a programme of selecting and training physicists, chemists and engineers was started in Mumbai under the leadership of Bhabha. This provided the growing atomic energy programmme with professionals; many research physicists also started their career here. In addition, many scientists who did their Ph.D. and subsequent research abroad returned to India. A number of centres of quality (universities and research institutes) had been training professional physicists since the twenties or so. Because of increased mobility and ease of communication, international collaboration as well as working abroad for some time became common. All this, along with a rapid growth in the number of physics based government supported institutions after Independence, led to a major expansion in physics; because of the relative sparseness of experimental research and the slant of the intellectual culture, there was (and is) a large thrust in theoretical physics. We mention below some contributions in areas such as particle and nuclear physics, gravitation and cosmology, condensed matter physics and statistical mechanics.

Theoretical particle physics has over the past half century gone through many stages. To all of these, Indian physicists have made significant contributions. Perhaps the best known departure was the hypothesis in the late fifties (1957) that the parity violating weak interaction and decay process is maximally so, arising phenomenologically out of a fermion current that is of the form (V-A), where V is a vector and A an axial vector. This (V-A) hypothesis, proposed after analyzing all available experiments (and inconsistent with a few of them, which were subsequently shown to be in error), was a breakthrough towards the present theory of electro-weak interactions. An early area of important activity was the formulation of constraints and sum rules on various elementary processes, using only general principles in the absence of a dynamical theory, with important results on scattering cross sections and amplitudes. In the phase where algebraic properties of quantum particle currents were analyzed, exact low energy theorems were obtained. Gauge field theory, quantum chromodynamics (QCD) and electro-weak unification leading to the standard model of fundamental particle interactions, have all seen important original contributions, ranging from results in relevant quantum field theories to

predictions and analyses of experiments. For example, it was shown quite early that the quanta of a massless Yang-Mills (gauge) field are confined (much before the advent of QCD). Very early, one loop (higher order) corrections to muon decay were obtained in gauge theory and shown to be finite. A lepton isolation criterion for the top quark was proposed as a means of detection, and prediction of its mass was made. Charged quantum solutions and charged vortex solutions were shown to be present in appropriate field theories. Various possible experimental signatures for detecting the quark gluon plasma in high energy collisions between heavy ions have been analyzed, and their uniqueness discussed. The consequences of the spin content of nucleons in several nuclear reactions were examined within the QCD. The detailed nature and implications of the chiral phase transition in lattice QCD were determined. Physics beyond the standard model, namely in supersymmetric models has been actively explored, both from a formal viewpoint (e.g. the solution to the naturalness or gauge hierarchy problem in supersymmetric field theories, this being a strong theoretical argument for such theories) and the approach of using high energy collision events to set limits on say masses of supersymmetric analogues of quarks, gluons, and Higgs bosons. Another fruitful area is at the active interface of cosmology and particle physics ; an early example is a limit on masses of weakly interacting particles such as neutrinos, from cosmological considerations (this was perhaps the first suggestion of the existence and relevance of dark matter in the universe).

In theoretical nuclear physics, a great deal of original work has been done on the microscopic approach to nuclear structure, especially the shell model. For example, relating the spectrum of a particle - particle and a particle - hole configuration, the magnetic moments of neighbouring nuclei could be connected, and an estimate obtained for three body nuclear forces. A method for reducing the nuclear three body problem to two body problems for separable potentials was used extensively for understanding few nucleon systems, and also for the three quark model for a nucleon. Some of the conclusions from the latter presage a new degree of freedom for quarks, now well known as 'colour'.

There is a long tradition of research in general theory of relativity and gravitation, earlier mainly in departments of mathematics. Some of the early major results are the exact solution of Einstein's equations for the case of any electrostatic field, and for a radiating star, as well as the equation which turned out to be the key ingredient in the proof of the black hole singularity theorems (Hawking and Penrose). Other important contributions were made to gravitation theory and cosmology, such as the development of steady state cosmology, various aspects of black hole physics, and the seismology of the sun based on its normal modes of oscillation.

In the area of condensed matter physics and statistical mechanics, activity started in the 1960's. An early result was the recognition that orbital ordering in Jahn Teller distorted oxides is an order - disorder transition, rather than displacive. It was shown that the exact ground state of an antiferromagnetically coupled spin system (for a particular ratio between nearest and next nearest neighbour couplings) is a dimerized superposition of spin singlets, an important signpost in quantum magnetism and a forerunner of spin singlet or resonating valence bond ideas for antiferromagnetism and high temperature super-conductivity. A theory of unusual time dependent specific heat and heat pulse propagation in glassy dielectrics at low temperatures was developed. Qualitative and quantitative consequences of quantum spin fluctuation effects in itinerant electron (fermion) systems with ferromagnetic transition temperature $T \sim 0$ were spelt out ; the related, presently active field of quantum critical phenomena developed a generation later. The theory of liquid to solid transition in (real) dense classical systems was developed, in terms of a new free energy functional of the density involving

known strongly nonlocal fluid phase correlations. This approach has proved of value in a number of phenomena in which both the fluid and the solid, as well as large deformations of the solid are involved.

Optical nonlinear susceptibilities for semi-conductors and at metal surfaces were predicted and calculated, as was also the prominent surface enhanced Raman scattering. The nature of ground state and excitations in coupled spin chains is a theme of continued activity. It is a field that has recently seen a very large amount of experimental work because of synthesized spin ladder compounds with unusual properties. Here, exact solutions for ground states for chains, ladders and special two dimensional systems have been obtained. Multimagnon bound states and solitonic excitations have been explored. Conservation laws for and exact integrability of one dimensional lattice electron systems with interaction have been discovered. A complete renormalization group based analysis of the properties of a magnetic impurity in a metal (Anderson model) as it evolves from weak to strong coupling with its environment on cooling was developed. An inverse orbital degeneracy expansion was proposed for Anderson model magnetic impurity systems, in the context of mixed valence and heavy fermions. The essentiality of 'hedgehog ' like spin defect textures for the ferromagnetic - paramagnetic transition in systems was shown. The long time relaxation behaviour of disordered ferromagnets was shown to be dominated by exponentially improbable ferromagnetic domains. The dependence of the area of the hysterisis loop in magnets on the size frequency of the reversing field was analyzed for the first time and power law relations obtained, the results being close to those known from the experiments of Steinmetz more than a century ago. The above account necessarily touches on a wide range of phenomena and models, reflecting the nature of condensed matter physics.

In other areas of theoretical physics, some of the major contributions are the following. In the 1950s, Pancharatnam, while exploring the description of the state of polarized light in terms of a vector with the tip on the surface of a 'Poincare' sphere, clearly understood and enunciated the idea of a geometrical phase (Berry phase; now often called the Berry-Pancharatnam phase) associated with changes of polarizarion described by the tip executing a closed curve on the Poincare sphere. Subsequent work includes extension to non-closed curves, kinematics and mathematical structure of the theory. In a contribution of central value to biochemistry and biophysics, Ramachandran and colleagues showed that dihedral angles between successive molecular groups in proteins are sterically constrained, and can lie only within certain regions of values (Ramachandran diagram). In the area of quantum optics, in addition to the basic coherent state representation of electro-magnetic fields, pioneering work has been done in areas such as cooperative resonance fluorescence, pair coherent states and squeezing etc.. Plasma physics is another area with significant Indian contributions, e.g. the theory of parametric instabilities and stabilization of tokamak ballooning modes.

The survey is concluded by mentioning some physics research facilities and achievements pertaining to the last decade or so. The attempted description will be grossly incomplete and patchy, since the physics community is rather large, with perhaps 5,000 or more Ph.D. physicists. Most major areas of physics are pursued, so that there is a large and widespread knowledge and research base. This base is formed by the sustained efforts of a large number of dedicated practitioners working under difficult conditions, and a relatively small number of prominent figures or leaders, some of whom have made contributions of major significance to physics. A few individuals have successfully built and/or nurtured major institutions and facilities, especially in government departments connected with atomic energy, space, defence etc. A culture of self-reliance of developing the tools needed,

and of applied science at a high level of competence in diverse areas, has been developed. In experimental physics research, a few fields stand out in terms of the investments made, and facilities created. These are overwhelmingly in the area of 'big' science. In the field of astronomy and astrophysics (as described in the Chapter on this area) a number of major facilities have been set up that are of world class and available widely to scientists within India as well as from abroad. A number of medium energy particle accelerators have been functioning in the country, e.g. a heavy ion accelerator in the Nuclear Science Centre, Delhi, used as a common facility in Nuclear Physics and Materials Science for all Indian universities for about a decade. A major tokamak facility using a solid state superconducting magnet is coming up at the Institute of Plasma Research, Ahmedabad. An ultraviolet synchrotron is operational at the Centre for Advanced Technology, Indore, and an X-ray synchrotron is expected to come on line soon.

There have been many interesting developments in experimental condensed matter/materials physics. The energy dependence of the electronic excitation spectrum near the T=0 metal insulator transition, with the possible development of a pseudogap, has been explored. While subsequent to the discovery of superconductivity in the cuprates, considerable amount of materials related work was done, the absence of quality single crystal growth and cryogenic facilities has proved a serious handicap in this as well as other areas. However, novel phenomena associated with flux lattice melting, plastic flow of the flux lattice etc. have been discovered (TIFR) using cuprate and other superconductor crystals grown elsewhere. The nature of atom (or molecule) light interaction in intense laser fields has been actively probed. Aspects of electronic and optical processes in quantum well semiconductor structures have been studied by several groups. An interesting new development in a field of basic interest as well as current activity is the detection and quantitative analysis of electrical noise near the metal insulator transition in silicon (universal conductance fluctuation), its suppression by electric fields and thermal dephasing. Very careful structural work on quantum and mixed ferroelectrics has greatly clarified the nature of phases in these; the phenomena and materials are of importance both scientifically and technologically. In the growing field of colossal magnetoresistance oxides (manganites) a large amount of well known work exploring the bewildering variety of electron driven phases and phase transitions has been done (mainly at IISc). Two notable features of this body of work are the fruitful collaboration between solid state chemists and physicists, and the systematic study of phenomena using several probes, e.g. transport, tunnelling, heat capacity, light scattering and EPR. Fullerenes (C60, C70....) and carbon nanotubes are another aspect of this kind of work. For example, in Y junctions of carbon nanotubes, rectification has been shown to occur; many unusual properties of single and multiwalled nanotubes are coming to light. We have here entered the completely quantum world of nanoscience where there are no boundaries between different areas of science, and between science and technology. However, facilities for sustained frontier work in this area are very poor. A growing concern in modern physical science is the study of 'soft' systems, such as colloids, membranes, foams, and gels, in which the energies associated with the relevant degrees of freedom are of low energy (~ kB T). Here, in addition to liquid crystals mentioned above, aggregates of colloids forming a glassy phase have been studied structurally (and kinetically), diffusion of photons in this medium has been analyzed, and surfactant based self-organized assemblies have been probed using light scattering.

In theoretical physics, the last decade has seen a wide range of contributions. In string theory, an area of great intellectual ferment, the Indian presence is quite prominent. While many of the developments over the decade had active Indian participation, at least two stand out because of the critical Indian contributions namely the idea of

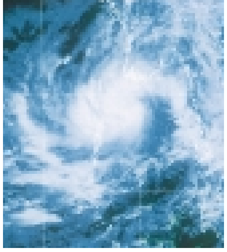
duality between strongly and weakly interacting string field theory, a major breakthrough in the field with wide implications and an absolute value for black hole entropy from a quantum model for it.

Contributions to theoretical astrophysics range from an analysis of shock wave induced triggering of starburst collections in interacting galaxies and a calculation of the selfconsistent (gravitational) potential at the core of elliptical galaxies to early discussions of gravitational lensing as well as nonlinear mechanisms for large scale structure formation in the early universe.

Indian theorists have contributed notably to ideas connected with high temperature superconductivity, e.g. the resonating valence bond model for antiferromagnetically coupled electron spins on a lattice and the associated gauge degree of freedom which are believed by many to be crucial ingredients in any theory. A long range one dimensional antiferromagnetic interaction model with exactly known ground state, and with 'spinons' was discovered a little more than a decade ago. The nature of interlayer tunnelling and consequences for the puzzling anisotropy of resistivity in the cuprates has been discussed. A very interesting proposal for a mirrorless laser in a disordered one-dimensional medium using (Anderson) localization properties has been made. A number of interesting contributions to mesoscopic physics, e.g. conductance fluctuations and persistent currents in mesoscopic structures, have been made. In the area of strongly correlated electron systems, the dynamical mean field theory has been extended in several significant ways, in particular going beyond the single site approximation to describe clusters. In what has now become a standard method in the field, it has been shown how photoemission data can be used to derive reliable and precise information about electron spectral density in cuprate superconductors.

In statistical mechanics, a unique exactly soluble model for self-organized criticality, the Abelian sandpile model, was formulated and the results analyzed. A number of interesting soluble models in low dimensions for interfacial dynamics were proposed and solved in the broad area of nonequilibrium statistical mechanics. Multiscaling behaviour in turbulence has been numerically explored. Chaotic control of cardiac arrhythmia is one of the many fascinating contributions to emerge from the increased attention given to nonlinear dynamics and chaos. Some others are chaotic computing, yielding of solids and premonitory phenomena in earthquakes. The nature of glassy free energy minima and their 'landscape', and a formal approach to freezing in disordered systems, are some efforts at understanding one of the major unsolved problems in condensed matter physics, namely the glass transition. In the area of equilibrium statistical mechanics, phase transitions in polymeric systems, the nature of the DNA denaturation / unzipping transition, and flux lattice melting are some of the notable efforts. Original work on autocatalytic networks as involved in prebiotic evolution has been carried out. Work on 'spin ice', namely dipolar interacting spin models with residual entropy (measured in some pyrochlores) as in some models of ice, has attracted attention.

The above incomplete survey suggests that physics activity in India continues at a high international level and over a widening range. While this is broadly true, there are a number of clear signs suggesting that immediate corrective action is necessary for the continued vitality, growth and usefulness of not only physics but science in general. These signs are briefly: (a) the generally poor state of experimental science (at least physical science) in India, due to continued lack of support for laboratory-scale physical science (by a factor of five or more), (b) relative paucity of physics related (high) technology, (c) the concentration of research in a small number of non-teaching institutions with few students, and the blighting of universities with many students, an inherently unstable arrangement not found in scientifically vigorous societies, and (d) a sharp decline in the number of students taking up physics.



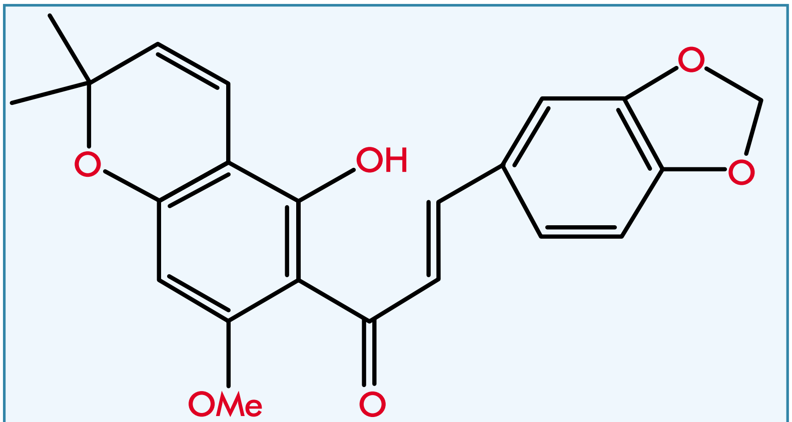
CHAPTER X

CHEMISTRY

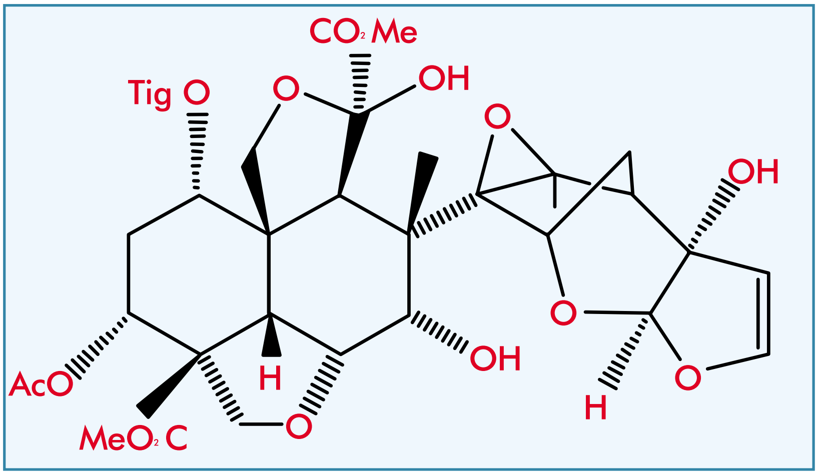
Research in chemistry has been actively pursued in the country for the past several decades. Indian chemists have made remarkable additions to basic knowledge and its applications. The number of chemists working in universities, national laboratories, other scientific establishments, and industries is very large. It is an uphill task to cover even the main achievements of chemists engaged in a wide spectrum of research pursuits. What follows is a short account that gives a glimpse into the enormous national endeavour in chemistry. The pioneering work by Acharya Prafulla Chandra Ray in the early twentieth century in Kolkata was responsible for the great turn of events in chemistry in the Indian subcontinent. The discovery of a stable mercurous nitrite composed of two relatively unstable ions, unfolding of the interesting chemistry of hyponitrite ion, synthesis of a large number of organic sulphur compounds, coordination chemistry of heavy transition metal ions, iridium, platinum and gold are some of the notable contributions of Prafulla Chandra Ray. He established the Bengal Chemical and Pharmaceutical Works in 1902 to manufacture mineral acids and pharmaceuticals through his own earnings and this forms the earliest entrepreneurial endeavour of Research and Development in the country. In the subsequent decades, the major thrust in chemistry was in organic chemistry, especially in the chemistry of natural products. In recent years, efforts have been made in several new directions in the various branches of chemistry.

In earlier years the chemistry of alkaloids, terpenes and steroids engaged the attention of Indian chemists. Synthetic drugs such as antimalarials, contraceptives, sulfonamides and sulfones received serious consideration. Synthesis of long chain fatty acids leading to partial synthesis of natural products was achieved. Noteworthy work was carried out in the country on terpenes especially those occurring in Indian plants. Extensive investigations were made on natural colouring compounds related to benzopyrones and anthroquinones. A large number of plant alkaloids and flavonoids were isolated and their structure determined. Several novel natural products characterized by unique carbocyclic skeletons and

Glabrachnomene, a furanoflavonoid isolated from Derris indica (formerly called Pongamia glabra).



intricate stereochemical features have been synthesized, particularly noteworthy being the diverse sesquiterpenes. In recent years, research in natural products has assumed immense importance from the point of view of drug discovery and bioassay-guided fractionation of extracts to identify lead molecules. A coordinated activity in the area of drug discovery has been initiated by the CSIR in various laboratories and institutions.



Structure of azadirachtin, a potent insect antifeedent compound and inhibitor of ecdysis, isolated from the seeds of the neem plant Azadirachta indica.

Synthetic organic chemistry has been pursued by many researchers. Synthetic design of novel polyhydranes is a major area in which substantial achievements have been made. Synthetic work on the platonic hydrocarbon, dodecahydrane, attracted the attention of the international scientific community. A number of new reactions and organometallic reagents based on silicon, chromium, boron, palladium and phosphorus. have been developed. One of the important aspects of research in organic chemistry has been the synthesis of several organic intermediates for the pharmaceutical industries in the country. This has directly benefitted the industries; the speciality chemicals and pharmaceutical industries have registered an export market of US $ 3.5 billion accounting for 11% of the total exports from India.

Among the accomplishments in organic photochemistry, the unravelling of the mechanism of photochemical reactions such as photoperoxidation, photomerization and photocycloaddition reactions are notable. A novel 'photothermal' metathesis strategy turned out to be a key element in the synthesis of complex organic molecules. Many important achievements have been made in the area of polymer chemistry. Synthesis of novel precursors for polymeric materials, polymer binders, hypergolic polymers and so on have been carried out. In addition to the synthesis of thermally stable polymers, several oligoesters were synthesized which when added to the plasticized PVC drastically reduced its inflammability. Research on speciality polymers with desired properties has been initiated in many laboratories.

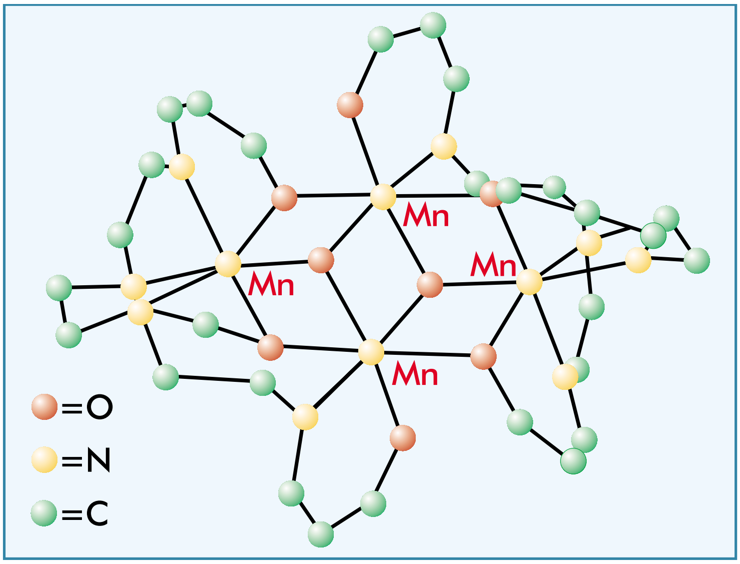
Studies on the synthesis of C_{60}-fullerene and its precursors by rational design resulted in the development of newer methods of making carbon-carbon bonds. Total synthesis of carbasugars having interesting biological activity has been pursued with vigour.

The importance of interface areas between chemistry and biology has been recognized. Attempts have been directed towards development of expertise in techniques for the cultivation of bacteria, isolation of bacteriorhodopsin and rhodopsin and synthesis of a few model retenoids.

Interesting work has been carried out by a few groups in peptide chemistry and several peptides of biological interest have been synthesized. Isolation and characterization of myobacillin, a new polypeptide containing 13 amino acids was accomplished. Nucleic acid research initiated in a few laboratories essentially focused attention on the understanding of the functions of DNA at the

molecular level and to generate nucleotides and novel reagents for site-specific modification of biomacro-molecules. Several studies have been initiated in the areas of biomembranes and metal ion interaction with biomolecules.

Green chemistry has gained great importance today. Several research groups have taken up this challenge and have been engaged in the synthesis of biologically active molecules. A large body of work has been generated in asymmetric synthesis in which a number of optically active naturally occurring terpenes and amino acids have been used as building blocks to get enantiomers of pure biologically active molecules.



Photosynthetic manganese --Modelling the assembly tetranuclear manganese -- Structure of a manganese salicylaldimine dication complex.

Work in the emerging area of supramolecular chemistry, molecular recognition systems, and design of multifunctional catalysts have become the focal point in some laboratories. The preparation of novel materials to perform specially designed functions has become a key feature. Significant advancements have been made in respect of nonlinear optical materials and precursors of MOCVD.

Analytical chemistry using organic chemicals as reagents has been a matter of special interest to many chemists in the country. Solvent extraction, development of sophisticated electroanalytical methods, pollution abatement in industrial workers, and water clarification are some of the important subjects in which research has been pursued. Several laboratories/centres providing analytical facilities have been established in the country.

Research in inorganic chemistry in the country in the last few decades has been considerable. Noteworthy contributions have emerged in the areas of coordination chemistry, bioinorganic chemistry, organometallic chemistry, chemistry of main group elements, spectroscopy and structural inorganic chemistry. The directions of research have been on the synthesis of novel systems for studies on multiple bonded metal-metal clusters, stabilization of low and high valent transition metal ions, homogenous catalysis, metal ion binding in macrocyclic and macropolycyclic ligand systems bearing several donor atoms such as oxygen, nitrogen, sulphur, selenium, tellurium and others. The development of model systems for mimicking the active sites of metalloenzymes and metalloproteins, metal-nucleic acid interactions, photosynthetic functions are some of the fields in which notable progress has been made. Studies on solution equilibria involving several metal ions with ligand systems of biological interest have been pursued vigorously. These have a direct bearing on the role of metal ions in biology and medicine.

Ingenious approaches have been made in the design and synthesis of organometallic systems for small molecular activation. The inorganic ring systems containing phosphorous, nitrogen, boron and silicon have been probed to elucidate the nature of multiple bonds in these systems. Considerable work has been carried out on organo tin and phosphorous compounds in view of their importance as insecticides and pesticides. Extensive

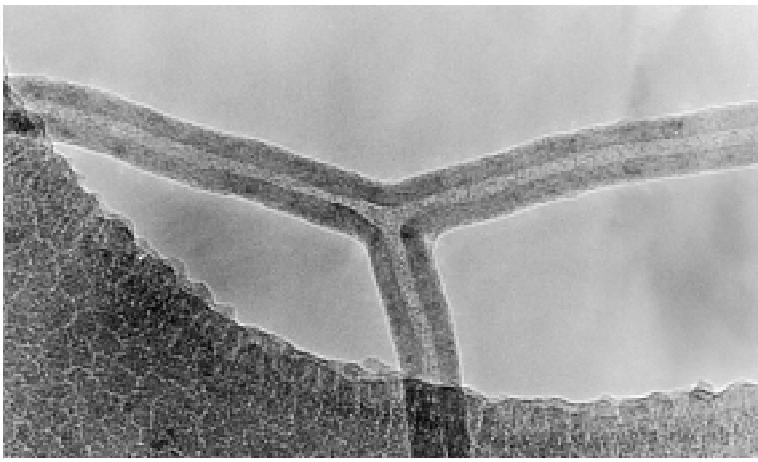
work has been carried out on metal alkoxides which are precursors of novel ceramics. Research in inorganic chemistry in the country is increasingly employing sophisticated spectroscopy (multinuclear NMR, EPR, and laser flash photolyser), structural (single crystal X-ray diffractometry) and electrochemical techniques.

Reaction mechanisms of both organic and inorganic systems have been pursued by several groups. Special mention should be made of the following: photochemical transformations, photoperoxidation, dimerization, quenching of fluorescence, emission spectroscopy of dyes, rare-earth complexes, conversion of solar energy, laser spectroscopy, photoisomerization, photocycloaddition and others. Research centres are being established in different parts of the country for the investigation of ultra-fast processes in chemical systems. Pioneering investigations have been made in the evaluation of rate constants of diverse reactions in free-radical polymerizations. There have been other significant achievements in polymer chemistry, kinetics and mechanism of photopolymerization, redox polymerization, crystallization of polymers, novel synthesis of polymers and polymer alloys and polymer fuels.

The application of quantum mechanics to chemistry started in India around 1950. Theoretical methods are being widely used to understand the structures, stabilities and reactivities of organic and inorganic molecules. New concepts, sophisticated formulations, mathematical theories (or models) in statistical and quantum mechanics, computational methods and strategies have been and are being developed for various static and dynamic properties of small and large systems both in ground and excited states. These include coupled cluster calculations, density functional methods, molecular modelling methods and theories of ultrafast processes.

A number of researchers are studying chemical thermodynamics, especially on equilibrium property measurements. Work on non-equilibrium thermodynamics is also being pursued by some chemists. The various aspects of electrochemical investigations include electrochemical energy systems, electrode kinetics, surface modified electrode systems, electroplating, and corrosion problems among others. Physical measurements on solid catalysts as well as studies of catalytic reactions have been carried out in several centres. The design and development of zeolite-based catalysts for industrial applications (especially for xylene separation) is one of the most significant achievements by Indian chemists.

Research in solid state chemistry, surface science and materials chemistry are being actively pursued. Notable contributions have emerged in the study of phenomena, structure-property relations and materials design. The materials include transition metal oxides, novel forms of carbon (fullerenes and carbon nanotubes), supramolecular assemblies, micro- and macroporous solids, nanoparticles and thin films and clusters. Special mention is made of the discovery of a simple method for fashioning aligned nanotube bundles and Y-junction nanotubes, which has received international acclaim in view of its application in electronic circuitry in the nano-

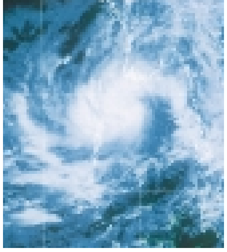


Y-junction carbon nanotube synthesized by direct chemical route. At the junction, the nanotube exhibits characteristics of a dioxide, thereby suggesting the potential of Y-junction nanotubes in nanoelectronics.

technology regime. The various aspects of solid state chemistry investigated include superconductivity, porous solids, structural and electrical properties, colossal magnetoresistance and charge density wave propagation. Many interesting findings emanating from research in these areas have made a significant impact in the international scene. The efforts have put India on the map of nanoscience research in the world.

Nuclear chemistry is mainly concentrated in the Bhabha Atomic Research Centre, but several groups in the country use tracer techniques. There has been considerable effort in radiation chemistry as well.

Techniques of magnetic resonance spectroscopy, electronic absorption and emission spectroscopy, Mo¨ ssbauer spectroscopy and electron spectroscopy provide support to organic, inorganic and solid state chemists and are engaging the attention of many physical chemists. Lasers have come to play a major role in research in the country. Mention must of made of areas, such as time-resolved spectroscopy of transitory intermediates, isotope separation, two photon spectroscopy, electron spectroscopy of surfaces, circular dichroism, resonance Raman, FT-IR, 300-5000 MHz NMR, solid state two-dimensional NMR, and photoacoustic spectroscopy which are being actively pursued at various centres in India.



CHAPTER XI

EARTH SCIENCES

The earth scientists of India, working in academic and research institutions, have endeavoured for an understanding of the geological architecture of varied terranes of the Indian subcontinent and their geodynamic development. On the other hand, the scientists of the government agencies like the Geological Survey of India, Oil and Natural Gas Corporation, Atomic Minerals Department, National Mineral Development Corporation, Central Groundwater Board and others pursued their primary agenda of exploring and seeking intelligent guidance for the search of mineral resources, including oil, gas and water. In the recent years, problems of environmental integrity and the security of ecologically sensitive and fragile terrains are being addressed with keen interest.

The founding of discipline-specific research institutions, like Birbal Sahni Institute of Palaeobotany, National Geophysical Research Institute, National Institute of Oceanography, Physical Research Laboratory, Wadia Institute of Himalayan Geology, and Centre for Earth Science Studies, have provided a great impetus for intensive research on diverse aspects of earth sciences. One of the good things that has happened in the post-Independence India is the coming into being of the Geological Society of India and its continuing efforts to project to the world the developments in India in the fields of geology, geophysics and geomorphology.

THE TERRANE-BOUNDING FAULTS OF INDIAN SUBCONTINENT

The Indian subcontinent comprises several geological provinces including cratonic blocks, each characterized by its distinctive structural setting, rock sequences and evolutionary history. These contrasted lithotectonic provinces or terranes are separated by fault zones of great length and depth. The identification and characterization of the zone of collision of India with mainland Asia, along what is today occupied by the rivers Sindhu (Indus) and Tsangpo (Brahmaputra), is one of the most important developments in the history of regional earth science

The ocean-floor basic-ultrabasic rocks along with seafloor sediments were forcibly squeezed up when India collided with mainland Asia. The junction of the collided continents is now occupied by the Sindhu river (Indus) in Ladakh.



studies. Known as the Indus-Tsangpo Suture (I-TS), the India-Asia collision zone embodies ancient ocean-floor and mid-oceanic basic and ultrabasic rocks, including sea mounts and island arcs, and deep-sea and oceanic-trench sediments of the Cretaceous age. Caught as they were between the vice-like grip of the collided and still converging continents, the lithological assemblages of the collision zone experienced severe deformation and high pressures of 9 to 11 kilobars (kb), as indicated by the presence of blueschists in Ladakh. The gravity anomaly pattern indicates that the northward-sliding Indian plate has bent down 10-15° in the zone 50 km south of the I-TS, with attendant detachment of the crust from the mantle, the latter sliding under Tibet and the former buckling up. The Main Boundary Thrust (MBT), sharply separating the Himalayan province from the Peninsular Indian Shield, is recognized as the plane along which the Indian Shield--along with its frontal sedimentary prisms of the Indo-Gangetic Plains and the Siwalik -- is sliding under the Himalaya. The faults of the MBT zone have been proven to be very active and the cause of the great earthquakes in the Himalayan region.

Characterized by the horst-and-graben structure, the Aravali mountain is delimited by NNE-SSW trending *en echelon* faults, including the 800 km long eastern Great Boundary Fault that in the north disappears under sediments of the Indo-Gangetic Plains, and the western boundary recognized as a subduction-related thrust characterized by ophiolites and plutons of granites, alkali rocks and ultrabasic-basic bodies. Movements along these faults account for the high seismicity of the Aravali domain. The basement complex, known as the Banded Gneissic Complex, includes metamorphic rocks that evolved at temperatures of 800-850° C and 650-850° C and pressures of 11-7 kb and 6.7 kb, in different parts. Related to the tectonics of the Aravali are the series of E-W trending arcuate faults in Kachchh that are locales of moderate to great earthquakes, including the one (Mw7.7) that occurred near Bhuj on January 26, 2001.

Another most significant finding was the identification of the great tectonic divide between northern and southern India along the margin of the Satpura horst mountain. Occupied by the rivers Narmada and Son, the Narmada-Son Lineament has been linked in the west with a transform fault in the Arabian Sea and in the east with the strike-slip Dauki Fault. The Dauki Fault, in turn, merges with the Naga Thrust that represents the subduction of the Indian Plate under the Myanmar-Malaysia Plate. This fundamental fault of ancient origin reaches the mantle as revealed by deep seismic sounding, and has influenced the deposition and deformation of Proterozoic Vindhyan and Early Phanerozoic Gondwana sediments.



The Karnataka Craton in the Southern Indian Sheild, made up of rocks as old as 3,000 million years and 2,500 million years, and thickly covered with laterite soil, has long been a stable land mass. The Kaveri river drops as water falls across the faults that are found to be active.

In the Karnataka Plateau, the Dharwar Craton, subdivided into eastern and western blocks by the NNW-SSE trending Chitradurga Shear Zone, is characterized by horizontal shortening and thrusting of ductile shearing during the Late Archaean period. This was followed by Dharwar sedimentation on a stable platform earlier and in an unstable mobile belt later. The green-schist belts in

the Shield are recognized as suture zones related to plate tectonics of the Archaean period.

The Bhavani-Moyar Shear Zone sharply separates the Dharwar Craton from the Southern Granulite Terrane in the south. It is responsible for the uplift and attendant exhumation of deep-seated rocks of the 2,500 m high Nilgiri massif, and continues to be active as evident from river ponding, recent sediment deformation and mild seismicity in the belt. The constituent rocks charnockites and granulites were formed as a result of intermittent influx of CO_2 in the lower crust where the temperatures were as high as 700-900° C and pressures 5 to 6 kb or even 7-9 kb. This is evident from thermodynamic phase-equilibrium and fluid-rock interaction studies. Further south, the Palghat-Kaveri Shear Zone divides the Southern Granulite Terrane into two blocks, the southern one being an Archaean-Palaeoproterozoic mobile belt characterized by widespread formation at 550 Ma (million years or Mega annum) of charnockites and coeval emplacement of alkali granites and syenites related to Pan-African events. The NNW-SSE trending Achankovil Shear Zone is an active fault zone responsible for the seismicity in Kerala.

Timing of the Evolution of Cratons

The U-Pb ages of detrital zircons in metapelites in the Indian Shield have been interpreted as marking the beginning of crustal development about 3,400 Ma years ago. In the Karnataka Craton the Pb-Pb 3,204 ± 30; 3,121 ± 63 and 3,400 ± 140 Ma gneisses are closely associated with samarium-neodymium (Sm-Nd) 3,191 ± 40 Ma Holenarsipur ultrabasic rock of an ancient suture zone. The Peninsular Gneiss is recognized as a composite and migmatized body covering a very large part of Peninsular India, including Bihar and Assam, and having the whole-rock ages between 3,100 and 3,200 Ma years. This includes the Pb-Pb 3,018 ± 61 Ma Bastar Gneiss in Chhattisgarh, the Pb-Pb 3,292 ± 51 Ma Singhbhum Granite, the 3,163 ± 126 Ma Bonai Granite in Jharkhand-Orissa, and the Sm-Nd 3310 ± 70 Ma Udaipur Granite, the last one associated with the 2,830 ± 59 Ma volcanigenic amphibolite within the Banded Gneissic Complex in Rajasthan. The rubidium-strontium (Rb-Sr) 2,500 Ma old acid volcanics occurring within the greywackes constrain the time-span of the Dharwar Supergroup from 2,800 to 2,600 Ma. The U-Pb 2,513 ± 5 Ma Closepet Granite in Karnataka and the 2,550 + 50 Ma old Bundelkhand Granite in Rajasthan represent a strong 2,500 Ma old geodynamic event of continental dimension. The Sittampundi anorthosite is regarded as a layered ultrabasic-basic complex or a mixed composite body that domed up as a result of alaskite intrusion during the Closepet period. The kimberlite plutons dated Rb-Sr 1,067 ± 31 Ma at Majhgawan, MP, and 1,090 ± 20 Ma at Wajrakaur, AP, the 850 to 1,250 Ma old alkaline plutons and carbonatites, and the 800-200 Ma old dyke swarms that straddle across the Palghat-Kaveri Shear Zone represent tectonomagmatic events of significance.

Reconstructing the Stratigraphic History

The lower Cuddapah Pulivendla unit is dated Pb-Sr 1,817 ± 24 Ma, the Pb-Pb age of the Vempalle dolomite is 1,756 ± 29 Ma, and the Kaladgi base is dated 1,800-1,900 Ma. These data constrain the lower temporal boundary of the Purana (Proterozoic) sedimentary succession in South India -- the beginning of the Purana Sedimentation. Rift-basin sedimentation in the Godavari-Pranhita domain is characterized by tectonogenic and volcanogenic emplacement in the earlier phase and carbonate-formation in the later part. The carbonates show considerable diagenetic modification, including cannibalistic dolomitization. The lower limit of the Vindhyan is placed at 1,400 Ma, as the 1,009 Ma old kimberlite pipe penetrating the lower Vindhyan tends to bear out. Recognition of aeolian sand dunes in the Upper Vindhyan has a considerable bearing for the understanding of palaeoclimatic condition in the Late Proterozoic. The cyanobacteria-built stromatolites developed spectacularly in the dolomites overlying the terrigenous sedimentary rock in Himachal and Uttaranchal place the very crucial carbonate horizon of the Lesser

Himalaya in the neoproterozoic (<1,000 Ma) period.

Palaeoflow directional studies in the Lesser Himalayan sedimentary succession in Himachal and Uttaranchal demonstrated that in the mesoproterozoic and neoproterozoic times the sediments of the Lesser Himalayan basin were deposited by the north-flowing rivers that drained the mountainous terranes of northern Peninsular India. The abrupt end of sedimentary succession throughout the Lesser Himalaya and Purana basins in the Peninsular India and the pronounced interruption in the parts of Tethyan Himalayan domain in the north, is taken as implying the end of sedimentation throughout the Indian subcontinent. The Lower Cambrian fossil assemblage in the sediments coupled with Rhenium-Osmium (Re-Os) age of black shale of the terminal Tal Formation, indicate the time of cessation of sediments a little after 552 ± 22 Ma as a consequence of the Pan-African Orogeny.

Interpretation of isopach maps indicating progressive northward thickening (to ~2,000 m) and palaeocurrent directions of the coal-bearing Gondwana sediments in the basins of the Godavari, Mahanadi and Damodar rivers have been interpreted as indicating a northward slope of the land which these rivers drained in the Permian-to-Triassic period. There was a northward reversal of drainage during the Later Triassic period.

The passage over convection plumes of the northward-moving Indian Plate generated hotspots in the subcontinent. While the 115 ± 2 Ma Sung Valley carbonatite and coeval Rajmahal Volcanics in the Sylhet-Rajmahal belt in eastern India are attributed to the Crozet Hotspot, the 67 to 62.5 Ma Deccan Traps covering a very large area in western India is linked with passage of the Indian plate over the Reunion Hotspot -- the one which gave rise to the Chagos-Lakshadweep oceanic ridge. Progressive southward younging of the lavas of Deccan Traps and their overstepping relationship bear out this deduction. The mineralogy and petrology of the Fe-Ti (iron-titanium) rich Deccan flood basalt indicate dominant role of crystal-liquid fractionation of picritic magma in crustal sills with characteristic open-system with magma chamber, affected by varying degrees of crustal contamination. It is inferred that the melts were formed at 35-45 km depth in the mantle where the pressures were 10-15 kb, as borne out by nodules of spinel-peridotite and dunite occurring in the Deccan lavas of Kutch. Associated alkaline ultrapotassic and acid intrusives occupy shear zones along the west coast, the Cambay graben and the Narmada-Son rift valley. Palaeomagnetic polarity-reversal study of the 2,500 m-thick succession, constrains the duration of the Deccan volcanism from 67 to 62.5 Ma. Remains of foraminifers, nanoplanktons and dinoflagelletes in the sediments associated with the lavas confirm that the volcanism straddles the Cretaceous-Tertiary boundary. Buried under the volcanics are the Maastrichtian regoliths with pedogenic carbonates in the Narmada Valley.

The magnetic polarity-reversal studies of the 900-1200m thick Neogene succession in Jammu, Himachal and Nepal showed that the Siwalik spans the temporal interval of 18.3 Ma to 0.22 Ma -- the Lower Siwalik 18.3 to ~10 Ma, the Middle Siwalik ~11 to 5.3 Ma, the Upper Siwalik 5.3 to 0.22 Ma. These chronological limits are in broad agreement with the boundaries fixed earlier on the basis of appearance and presence of vertebrate fauna.

Benchmarks in the Evolutionary History of Life

The appearance of Lower Cambrian (Tommotian-Botomian) fauna including the protoconodonts that had developed grasping mechanism, conodonts, trilobites and small shelly fauna in the 522 ± 22 Ma black shale, limestone and phosphorite of the Tal Formation in Uttaranchal, marks the beginning of the invertebrate life in the Indian subcontinent. The vertebrate fauna from the Kundaram horizon in the Pranhita-Godavari Valley, known for prosauropod dinosaurs, testifies to the coming of the dinosaurs by the Late Permian age. The dinosaur skeletons in the Jurassic beds in Kutch, the eggs of Titanosaurids in the Narmada Valley, and the recent find of dinosaur fossils from southern Meghalaya, define the large

domain that the dinosaurs ruled in the land then.

There were drastic changes in the structure and evolution of over 80 per cent of both the land and marine organisms at the transition of Upper Cretaceous-Lower Tertiary period some 66 million years ago. Several successful and well-established groups, including the dinosaurs, disappeared altogether, while nearly 20 per cent new groups, including foraminifers, mammals and flowering plants, became dominant and diversified in the Tertiary period. The mass extinction was quite gradual spanning over 2-3 million years. This event, marked in the boundary beds by anomalously high amount of iridium, is attributed also to the impact of gigantic meteorites or comets.

The joining of India with mainland Asia opened the gates of immigration of a variety of terrestrial fauna from different parts of Eurasia. The first appearance in the early part of the Himalayan foreland basin (Subathu) of the mammals which have a striking resemblance and close affinity with those of Eurasia, indicate that by ~ 49 million years ago, a land-bridge between Eurasia and India had been established.

The finding in the upper part of the Kuldana-Subathu succession in northwest Himalaya of the *Himalayacetus subathuensis*, an animal representing the transition from the terrestrial mammal to the marine mammal, at 53.5 Ma, and of *Ambulocetus natans* shows that it was in the sub-Himalayan domain where the whales first evolved.

The expansion of grasslands in the Siwalik realm attracted grazing animals from neighbouring lands -- from as far as Africa, Europe and Central Asia. The immigration of quadrupeds brought about major faunal turnovers in the period 7.5 to 9.5 Ma. The invasion of exotic fauna and resultant marginalization or even extermination of the indigenous animals such as rhinos, buffaloes and cows, brought about substantial changes in the composition of the Siwalik life. *Hipparian*, the pigs, the bovid *Selenoportex*, the proboscid *Stegodon*, the hippopotamus *Hexaprotodon*, the elephant *Elephas planifrons* and the horse *Equus*, came from different parts of the world -- Africa, Europe and Alaska -- in different times between 9 and 2.5 million years ago.

Significant is the finding of skull of the human *Homo erectus* from the Middle Pleistocene sediments in the Narmada Valley.

Emergence and Evolution of Himalaya

Following the contact of India with Asia ~ 65 million years ago and their complete welding by Ma, there was a resurgence of very strong tectonic movements in the period 25 to 18 Ma ago. The northern part of the Indian plate broke up all along its 2,500 km length. The southern plane of breaking (main Central Thrust) is perceived as the contact between the high-grade metamorphic rocks with mid-Tertiary granites and low-grade metamorphic rocks intimately associated with 1,900 ± 100 million year-old porphyroids. The northern discontinuity (Trans-Himadri Fault or Zanskar Shear) marks the plane along which the Phanerozoic Tethyan sedimentary cover got detached from its foundation of the Great Himalayan high-grade metamorphic rocks. The Great Himalayan metamorphic rocks evolved at a depth of 25 to 30 km under pressure of 6 to 10 kb (locally up to 12 kb) and in the temperature range of 600°C to 800°C. These are injected with and pervasively migmatized by anatectic granite characterized by high strontium isotope ratios, and presence of sillimanite, garnet and cordierite. They were emplaced in the period 25 to 18 Ma, the peak granitic activity occuring at 21 Ma.

Concordantly folded with the Lesser Himalayan Proterozoic sedimentary succession, the Lesser Himalayan metamorphic rocks, occurring as thrust sheets or nappes, travelled different P-T-t paths, as evident from the range of temperature 250°– 450° C and pressure conditions of 3 to 6 kb. Synmetamorphic ductile shearing of the thrust succession has been explained as the cause of inverted metamorphic successsion.

The magnetic polarity reversal studies put the upper limit of the youngest marine sediment of the Subathu Formation at 42.6 Ma, and the commencement in the continental setting of fluvial sedimentation

represented by the Dagshai (Lower Dharamsala) at 23.55 Ma. This suggests a gap of nearly 15 million years. However, recent dating of 36-40 million year-old heavy minerals in the basal sediments indicates that the gap is not that big. Patterns of sediment dispersal and palaeocurrents indicate that there was in the Oligocene a drastic reversal of the direction of drainage from the earlier northerly or northwesterly to the present southerly and southeasterly. This development implies that the Oligocene tectonic upheavel created a water-divide in the Himalayan provice.

In the Kailas-Kargil belt along the India-Asia collision zone more than 2,000 m-thick succession of conglomerates and sandstones was emplaced in the channels and flood plains of rivers that alternately meandered and flowed as a braided system. Remains of palms, rosewood and charophytes indicate a warm-moist climate prevailing in the then Sindhu-Tsangpo floodplains that could not have been higher than 2,100 m above the sea level. The vertebrate fauna, including crocodiles, turtles, python-like snakes and mammals (goat and deer) of strong Eurasian affinity assign the sedimentary succession to the period from the Later Upper Oligocene to Middle Miocene time.

The chronological limits of the Siwalik are put at 18.3 Ma and 0.22 Ma on the basis of magnetic polarity reversal studies carried out in Jammu, Himachal and Nepal. The rate of the Siwalik sedimentation is estimated to be very fast, varying from 10 cm/1,000 yr. to 71 cm/1,000 yr. The great volume of sediments brought by the Himalayan rivers converted the neogene Siwalik Foreland Basin into extensive floodplains in which rivers migrated laterally, formed coalescing aprons, and built multistoried sand complexes. Intense compression of this basin at ~ 0.8 Ma culminated in the emergence of the Siwalik Hills in the north, the breaking up of the basin along what is known as the Himalayan Frontal Fault, and the development of subsiding Sindhu-Ganga-Brahmaputra Basin in the south. Filled up with sediments, it eventually became the Indo-Gangetic Plains.

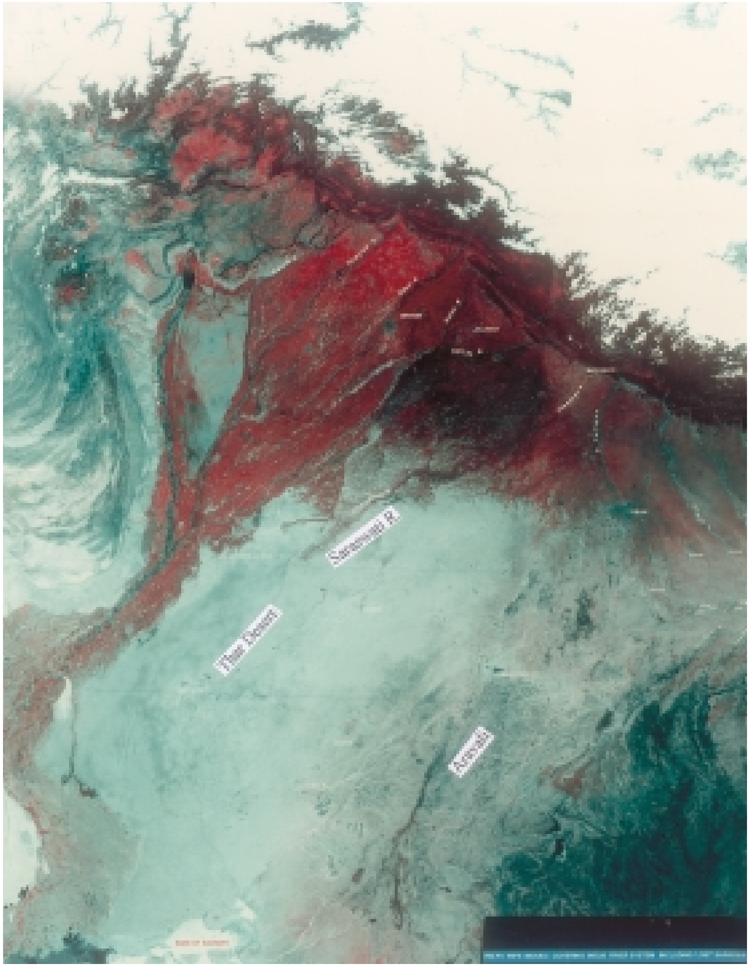
Most of the major faults of the Himalaya are proved to be quite active . This is borne out by dismemberment, dislocation, uplift and deformation of Late Quaternary fluvial terraces, colluvial fans and cones, and lacustrine flats in many parts of the Himalaya. Movements on active faults caused blockage of rivers and streams and formation of lakes practically in all the four terranes of the Himalaya. Radiocarbon dating of the basal clays of the palaeolakes and thermoluminescence dates of the gouges in the shear zones of the causative faults suggest that the lakes originated in the period 60 and 40 ka.

The lacustrine deposits preserve records of the change of climate in the Late Quaternary. The wet-cold phase alternated with dry hot spells a number of times all over the Himalayan province. It was a warm-wet spell between 6,000 and 4,000 yr B.P. and the 3,500-2,000 yr B.P. was a time of considerable dryness throughout the Indian subcontinent.

Impacts of Continuing India-Asia Convergence

The GPS geodesy has established the rate of India–Asia convergence at 54 ± 4 mm/yr. Only about 30 per cent (e.g. 18 ± 2mm/yr.) of India-Asia convergence is absorbed across the Himalaya, the average rate of accomodation derived on the basis of slip rates of great earthquakes being ~17 mm/yr. Recent GPS measurements along the Delhi-Malari and Delhi-Milam sections across the Kumaun Himalaya show that the Tethyan domain beyond the Great Himalaya is advancing southwards at the rate of 18 to 20 mm/yr. The Great Himalayan terrane is rising at much faster rate of 7 ± 2 mm/yr. in northcentral Nepal. Relevelling by Survey of India demonstrated that the Siwalik terrane in the Dehra Dun Valley in the central sector is rising at the rate of 0.8 to 1.0 mm/yr.

The Aravali mountain is registering a slow rate of uplift, as evident from the deflection of the rivers, including the Yamuna eastwards and the Satluj westwards. Saline lakes of the desert realm in Rajasthan resulted from segmentation of river



The tectonically resurgent Aravali Range, trending NNE-SSW, was responsible for the deviations and deflections of the Himalayan rivers including the legendary Saraswati, that is now represented by the dry channels of Ghaghar River. The Ghaghar loses itself in the vast desert of the Thar in the west.

channels along NE-SW trending faults related to the active faults of the Aravali domain. The Gujarat Plains of the Sabarmati and Mahi rivers are, likewise, experiencing impacts of neotectonic movements, including shifting of river courses. The abandoned channels offer good potential for reserves of water.

The Dharwar Craton in the southern part of the Indian Shield is much more dynamic than previously thought. Cut by active faults trending NNE/S- SSW/S in the eastern part of the Dharwar Craton and NNW/N-SSE/S in the west, the strike-slip and oblique-slip movements gave rise to horst mountains -- the Biligirirangan-Mahadeswaramalai in the east and the Sahyadri in the west. Synchronously, the breaking up of the NNW-SSE striking linear fault-blocks along the ESE-WNW oriented reverse faults and shear zones was responsible for the peculiar en echelon configuration of the high ranges of the Sahyadri and its escarpment the Western Ghat. The buckling and breaking of the crust of the Southern Granulite Terrane along the E-W oriented reverse faults and shear zones culminated in the emergence of the >2,500 m-high Nilgiri Hills. Strong fluvial response to active tectonism including stream ponding, indicates Late Quaternary reactivation of ancient shear zones and faults of the Southern Indian Shield. The time span of the formation of palaeolakes in the Mysore Plateau and the Nilgiri Hills implies Late Pleistocene to Middle Holocene reactivation of the causative faults.

Analyses of teleseismic waves indicate the presence of an anomalously thick (4 to 5 km thicker low-velocity (1-3 per cent) crust beneath the Kodaikanal granulite terrane adjoining the complex of gneisses and granites. This is interpreted as implying underplating related to continent-continent collision, resulting in the evolution of a granulite terrane in the proterozoic belt.

The pattern of epicentral distribution indicates that the Himalayan earthquakes are related to the movements on the MBT -- and its subsurface northward extension , and to the multiplicity of tear faults that cuts the Himalaya transversely. There is an approximately 50 km wide belt of predominant moderate earthquakes (M 5 to 6) located in the inner Lesser Himalaya just south of the MCT. Intense microseismicity also tends to be clustered in this

belt, just in front of the Great Himalaya. The depths of hypocentres are quite shallow -- commonly 25 to 20 km. The hypocentres define a shallow-dipping detachment plane which separates the subducting basement from the overlying sedimentary wedge.

The seismicity is confined to the fault-delimited horsts, grabens and transcurrent lineament in Peninsular India.The level of strain accumulation in the whole of Southern Indian Shield is quite low – less than 10 manostrains/yr., implying the release of strain by slow movements on active faults.

Belts and Modes of Mineralization and Mineral Deposits

Most of the mineral deposits including those of rare-earth elements are intimately associated with the thermodynamics and hydrothermal processes related to the rifting of lithosphere and the subduction of plate. Characterized by wide shear zones, the subduction zones have been found to be particularly favoured locales of mineralization. Among the big discoveries that have influenced the resource scenario in the country are the following: the Jaduguda-Bhatin-Naroapahar uranium belt in the Singhbhum Shear Zone, the giant copper (-molybdenum) deposit of Early Proterozoic age in the granitoid rocks at Malanjkhand, M.P., the East-Coast bauxite province, the world-class zinc (-lead) deposit at Rampura-Arucha, Rajasthan, the world's largest barite deposit at Mangampet, A.P., the sandstone-hosted uranium at Domiansat, Meghalaya, and the Proterozoic 'unconformity-type' uranium deposits in the basal Cuddapah at Lamapur, A.P. and in the Bhima Basin.

Recent researches have shown that the main source of hydrocarbons in sedimentary sequence is the vegetable debris, including phytoplanktons, algae and lipid-rich plant remains derived from land as well as marine realms. The Bombay High basins of shelf carbonates (Palaeogene-Holocene) represent very productive offshore synsedimentary grabens containing marine, paralic and continental-facies sediments. The payzones are invariably associated with unconformities and diastems.



The 26th January 2001 earthquake of Mw 7.7 was the latest of the many large earthquakes that ravaged Gujarat in the last 10,000 years. This seismite seen underground near Vadodara was formed when the sediment got remobilized due to severe ground shaking.

The finding of heavy oil in the Cambrian rocks in the western part of the Bikaner-Nagaur Basin in northwestern Rajasthan has added a new dimension to the philosophy of search for petroleum, calling for reinvestigation of the Precambrian-Cambrian boundary sequences in various intracratonic and continental-margin basins, including the offshore continental shelves.

Developments in the Indian Ocean

In the Bay of Bengal, the Eightyfive East Ridge was formed in the Palaeocene period along the spreading axis as a result of a hotspot volcanic activity. A deformation zone extending from the Central Indian Ocean up to the northern Ninety East Ridge marks the diffuse boundary between the Indian and Australian plates. The northern part of the Indian Ocean experienced repeated tectonic deformation, stresses and N-S shortening as testified by folds and faults in the sedimentary cover of the crust, 7.5 Ma, 4 Ma and 0.8 Ma, with a cyclicity of 3.5 million years. Development of submarine NNW-SSE trending grabens and ridges and marginal basins on the marginal shelf and slope of south-

western India tend to corroborate this deduction. The NNW-trending magnetic lineaments marking anomalies have been interpreted as representing a two-limbed sea-floor spreading sequence in the interval 84 to 65 Ma in the Laxmi Basin in the northern Arabian Sea.

Nearly 8,500 m thick sedimentary succession overlying the Early Cretaceous oceanic basement is characterized by four unconformities -- Lower Eocene, Upper Oligocene, Upper Miocene and Upper Pleistocene. The sediment pile of the Bengal Fan documents excessive influx of sediments in the Bay of Bengal at about 10.5 Ma, 8 Ma, 2.6 Ma and 0.8 Ma, primarily derived from the Himalaya. The influx rate increased from 20-70 m per million year to more than 200 m/m.y. suddenly about 0.8 m.y. ago, obviously due to abrupt uplift of the Great Himalayan domain. In the inner shelf off the southwestern coast of India, the rates of sedimentation are very low -- 0.72 and 0.56 mm/yr at the water depth of 35 and 45 m respectively.

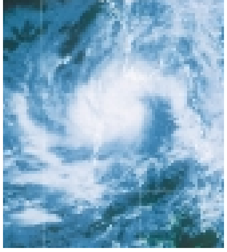
Oxygen isotope ratios of Palaeogene foraminifers of the western coast indicated cooling down of sea water from 32° C in the Early Eocene to 20° C in the Early Oligocene, and then a rise to 25° C. The oxygen-isotope systematics coupled with analysis of the Neogene planktonic foraminiferal assemblages of the Central Indian Ocean and the Arabian Sea indicated change in the chemistry of water and its cooling as a consequence of influx of cold water from Antarctica Sea at 22 Ma, 14 Ma, 12 to 10 Ma, 6.2 to 5.2 Ma and 1.8 Ma. Quantitative abundance of radiolarian and foraminiferal assemblages in the Arabian Sea, throw light on the palaeoclimate changes in the ocean realm. The characteristic radiolarians and foraminifers in the sediments in the northwestern Arabian sea, exhibiting distinct geochemical and biological changes, indicate strong upwelling, induced by southwesterly winds which led to the onset of monsoon about 8 ± 1 million years ago.

In the field of marine mineral resources, India has acquired the pioneer investor status over nearly 1,50,000 km^2 area in the Indian Ocean for mining polymetallic nodules -- ferromanganese nodules rich in cobalt and copper sulphides. The high-grade Pleistocene phosphorite and Holocene phosphatized limestone, with glaucony-phosphatic sediments on the western continental margin that show influence of microbial activities, provide a Quaternary analogue of the Precambrian phosphorite deposit.

Shallow seismic reflection surveys indicated presence of methane-charged sediments in the inner continental shelf off the western coast 10-20° N. Nearly 2.60 million tonnes of gas is estimated to be trapped here. The seismic profiles on the outer continental shelf's middle slope show the existence, 500-600 m below the sea floor, of deposits of gas hydrates, the source of methane.

From the lowest level, 150 m below the present sea-level around 18,000 yr B.P. during the Last Glacial Maximum, the sea water has been rising intermittently all through the Holocene. If it stood 25 m below the present during 8,000 to 7,000 yr BP in the Visakhapatnam area, it was 2 to 5 m above the present at 6,000 yr BP in the Rameshwaram sector on the eastern coast. On the westesrn coast the rise of sea level has been quite rapid in the interval between 9,000 to 7,000 yr BP, when the whole of the Rann was inundated by sea water and thus connected with the gulfs of Cambay and Kutch.

The Ganga-Brahmaputra rivers together annually transfer ~ 1,000 tonnes of uranium to the sea – which is ~ 10 per cent of the estimated global supply. The dissolved uranium concentration of ~ 2 μg/1 (compared to the global average of 0.3 μg/1) is thus a conspicuous characteristic of the Ganga water. In the Bhagirathi and the Alaknanda waters the dissolved ^{238}U content is typically ~ 2μg/1 while the ^{226}Ra content is 0.2 dpm/1. The rate of weathering (~ 2 kg/km^2/yr) of uranium (comparable in the Yamuna, Ghaghra and Gandak basin) is two orders higher than that in the Amazon and Congo basins. The ^{87}Sr/^{86}Sr value of the Alaknanda, Bhagirathi and their tributaries varies between 0.7300 and 0.7986. The Ganga mean of 0.7239 is higher than the global average of 0.7119.



CHAPTER XII

METEOROLOGY AND ATMOSPHERIC SCIENCES

The growth of Meteorology and Atmospheric Sciences in the last fifty years in India is an outcome of many diverse features and has been shaped by circumstantial changes, not necessarily related to science, such as World War II or the partition of the country.

The Meteorological Department of India also referred to as the Indian Meteorological Department (IMD) has been for over 125 years, the premier Government Agency for all matters concerned with the weather and its application to other allied fields. Just prior to the War the IMD had seven Regional Meteorological Centres (RMCs). They were located at New Delhi, Mumbai, Kolkata, Chennai, Nagpur, Lahore and Karachi, the last two were later transferred to Pakistan. Its organizational set-up, primarily service-oriented, in reality has effectively helped to foster theoretical research in Meteorology.

One of the interesting features of meteorology is the wide variety of different disciplines that it covers under its umbrella. Thus, apart from weather prediction on different scales of space and time, it also covers subjects that are associated with natural hazards, such a, seismology (earthquakes), the hydrometeorology of floods and droughts, geomagnetism, and agricultural meteorology. These are the different facets of applied meteorology. On the other side, the theoretical aspects are concerned with the analyses of data, predictability on different scales, especially of the monsoons, rainfall variability, the coupling between the atmosphere and the oceans, tropical cyclones and meteorological instrumentation. For research on these different facets, different directorates have been formed under the IMD in recent years.

Considering the high frequencies of tropical cyclones, in the northern sector of the Bay of Bengal, a Storm Warning Radar was set up at Kolkata airport in 1954. To facilitate the rapid transmission of cyclone warnings and other data for operational use between principal meteorological centres of the world, a World Weather Watch Scheme was drawn up by the World Meteorological Organization (WMO) in the late 1950s. Under the aegis of this scheme, high-speed telecommunication links were set up between Moscow and New Delhi in 1961. These focal points for high-speed data exchange were named as the Northern Hemisphere Exchange Centres (NHECs) by the WMO and New Delhi was selected a centre for this purpose. Along with centres for the rapid exchange of data, a similar scheme was drawn up for establishing a set of Northern Hemisphere Analysis Centres (NHACs), and New Delhi was again selected by WMO to be a Principal Analysis Centre for the Northern Hemisphere in the early sixties. In addition to centres for Data Exchange and Analysis, a separate centre for the study of seismology was set up in 1961. A.N. Tandon, a distinguished seismologist, became the first Director of this new centre.

Around this time, space-based data collection platforms began to be introduced. This added a new

Meteorology in India

- The main progress in the post-war years have been in (a) Satellite meteorology, (b) Radars and (c) Computer simulation and models.
- Data are now available on water vapour in addition to other variables on real time. The network of coastal radars has been enhanced, and a MST radar provides valuable data on wave propagation in the upper atmosphere.
- A National Centre for Medium Range Weather Forecasts (NCMRWF) and an Indian Institute for Tropical Meteorology (IITM) have been established.
- A number of monsoon-related field experiments have been conducted, with Indian coastal research vessels over a marine surface.
- Studies on rainfall variability, and the impact of snow cover are in progress

dimension to meteorological data. The first Weather Satellite, Tiros-I, was launched by the United States in 1960. To analyse the data from this new source, two centres were set up, in Mumbai and Kolkata airports, in 1964. In 1970 and 1971, two additional directorates were set up for Meteorological Telecommunications and Satellite Meteorology and, in 1974, the NHAC became an Area Forecast Centre for meeting the requirements of South Asian countries for aviation meteorology.

In this manner, the first twenty-five years after the end of World War II, was a period of rapid expansion. The IMD was transformed into a major international centre.

Recent Expansions

The next twenty-five years saw further expansion of meteorological services along with research and academic institutes. The number of cyclone warning centres was enhanced, and the number of upper air stations for probing the upper atmosphere was increased.

Of special significance was the creation of an Indian Institute for Tropical Meteorology (IITM) at Pune and a National Centre for Medium Range Weather Forecasts (NCMRWF) at New Delhi. The former was oriented towards research, while the latter was established to meet the increasing needs of weather forecasts for agriculture.

Courses of study in meteorology and atmospheric sciences were started at a number of universities and technical centres. New Centres for Atmospheric Sciences (CAS) were opened at the Indian Institute of Technology (IIT) at New Delhi, at Kharagpur in West Bengal and a Centre for Atmospheric and Oceanic Studies at the Indian Institute of Science (IISc) in Bangalore. A few universities, such as, the University of Calcutta, have introduced courses in meteorology within the department of physics.

The question which we need to ask ourselves at this stage is: What are the benefits in terms of research and applied science that have emerged out of this investment? And, what are the future targets that we must achieve? In this context, it is relevant to state that our progress in the last 50 years owes a great deal to the foundations laid by eminent scientists of an earlier generation.

The first Indian Director-General of Meteorology, S.K. Banerji, who succeeded Sir Charles Normand, an eminent British meteorologist whose work on the thermodynamics of the atmosphere was well recognized. Another eminent meteorologist from Britain was Sir Gilbert Walker. He gave up a senior academic position at the University of Cambridge to become the Director General of Meteorology in India. It was Walker who introduced the Indian mathematical prodigy, Ramanujam to G.H. Hardy at Cambridge. This led to his rapid recognition. Walker's outstanding discovery was thatt in the Southern Oscillation a see-saw pattern of pressure changes occur between the Pacific and Indian Oceans.

S.K. Banerji, an eminent seismologist, was the first to analyse the impact of topographic barriers

on the Indian summer monsoon. Another eminent Indian meteorologist was K.R. Ramanathan, the first Indian to receive the IMO (International Meteorological Organization) prize from the WMO who did pioneering work on the upper atmosphere, especially on the height of the tropopause at low latitudes.

Several eminent meteorologists from India won recognition in the post-war period, and some were pioneers in their areas, P.R. Pisharoty and P. Koteswaram being prominent among them. Pisharoty is the second Indian to be awarded the IMO prize by the WMO, for his contributions which included the computation of fluxes of water vapour across the Indian Ocean. P. Koteswaram will be remembered for his discovery of the Easterly Jet Stream a narrow band of air moving from the east towards the west in the upper atmosphere prior to the arrival of the monsoon over India.

A positive feature of its research has been the ability of the IMD to manufacture its own specialist equipment to a large extent, in the two workshops it maintains in New Delhi and in Pune. Original contributions were made by L.S. Mathur and S.P. Venkiteswaran, and the Indian radiosonde stands as an example of the joint effort made by them.

Progress on both the theoretical and instrumental aspects of meteorology in India has been through collective effort by a team. This tradition is still maintained.

Seismology and Geomagnetism

These disciplines do not have much in common with meteorology, but it was an eminent seismologist who first created an interest in tropical cyclones. Around 1930, S.K. Banerji suggested that cyclones in the Bay of Bengal could be detected and tracked by the microseisms on the seabed. This idea was followed up by many seismologists, notably by A.N. Tandon in 1957 and his associates, but was eventually given up because the cyclones could not be detected by this technique until they were very near the coast.

But work along similar lines continued, and recent advances in geomagnetism have helped us to understand the upper reaches of the atmosphere. S.K. Mitra's book *The upper Atmosphere* is now a classic on the propagation of waves in the upper atmosphere. A centre for research on geomagnetism at Colaba (Mumbai) had distinguished scientists like S.L. Malurkar and B.N. Bhargava who worked in this field.The recent book *Earth's Magnetic Field* by Girija Rajaram and P.R. Pisharoty, 1998, describes valuable links between geomagnetism and the upper atmosphere.

Satellite Meteorology

(a) The principal Indian achievements in the last three decades have been in three sectors:(i) satellite meteorology, (ii) weather radars (iii) computer simulation and numerical models for prediction. The achievements in satellite meteorology were an outcome of close collaboration with the Indian Space Research Organization (ISRO) when India began receiving the earth's images through its own geosynchronous satellites (INSAT Series) from 1982. In the early years, the imageries were received through different channels in the visible and the thermal infrared bands of the electromagnetic spectrum. But, very recently another satellite has been launched with two meteorological payloads: a Very High Resolution Radiometer (VHRR), and a Charged Coupled Device (CCD) camera. The VHRR payload provides imageries in two channels, while a third channel is used to measure the water vapour content of the atmosphere. The current resolution varies from 8 to 12 km. The data consist of the following meteorological variables:

I. Cloud Motion Vectors,
II. Sea Surface Temperatures (SST),
III. Estimates of Precipitation,
IV. Outgoing long wave radiation, and
V. Aerosols

The data provided gives valuable information for weather prediction, especially for the study of tropical cyclones and associated clouds. The information on aerosols is also important because

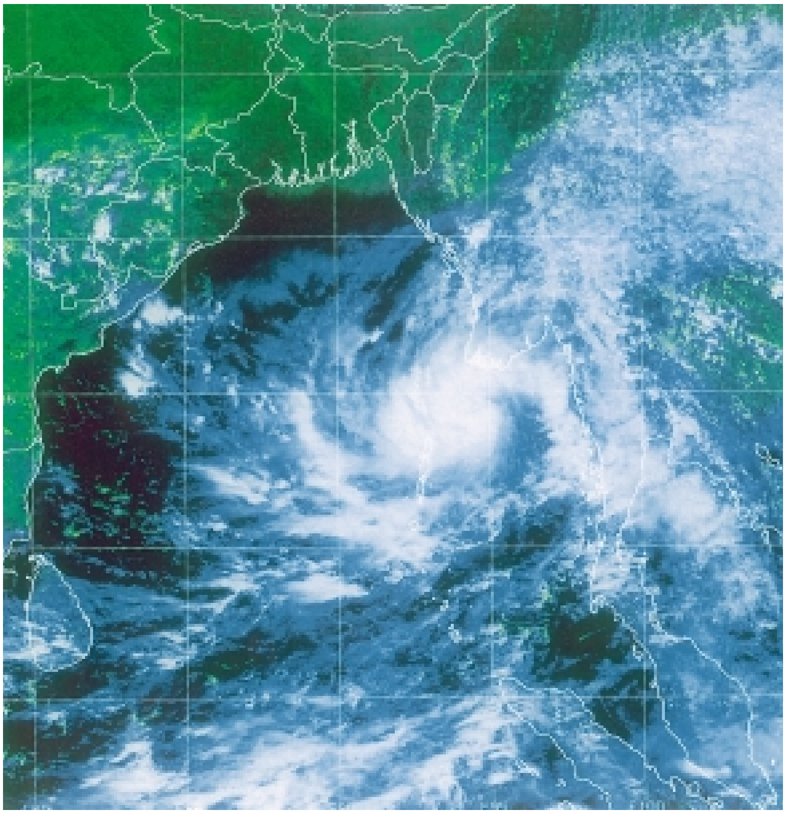


Photo: IMD and NCMRWF, New Delhi

Spirals round the cyclone centre.

of their role in the condensation of vapour within clouds.

The estimates of precipitation from satellite cloud imageries is likely to reveal more details on cloud transformation, and interactions between clouds in the near future. It is also interesting to recall that the D.N. Sikdar, a scientist with the IMD who migrated to the University of Wisconsin in the USA, had been one of the earliest in the team of scientists in the USA, who embarked on this project. Estimates of precipitation are based on measurements of the rate of change in a cloudy area, from satellite-derived imageries. Extension of this technique to multiple clouds, or clouds that interact with each other will open up further research possibilities. This will be of interest to India because of the substantial damage caused by thunderclouds.

Satellite imageries are also turning out to be very useful for detecting biomass burning and forest fires in different parts of the country. This is a natural hazard about which not much is known at present.

Weather Radars

In the last two decades, the detection of oncoming cyclones has become much more easier due to a close network of coastal radars. These radars operate on a wavelength of 10 cm, and have a range of about 400 km.

Radars operate on a system of transmission and reflection of radio waves from an object. The radiation from a radar antenna is polarized. In some radars it is possible to measure the reflectivity of an obstacle which could be in the form of a raindrop or a cloud. The horizontal motion of drops in the sampled volume of air leads to shifts in the frequency of the reflected signal. A Doppler radar measures this for the detection of cyclones.

The Mesosphere-Stratosphere-Troposphere (MST) Radar

A radar which is meant for studying wave propagation in that part of the atmosphere which extends from the troposphere to the stratosphere and, finally, to the mesosphere is referred to as the Mesosphere, Stratosphere, Troposphere or MST radar.

An MST radar became operational at Tirupati in 1994 and an extensive scientific programme has been drawn up for it, including one for studying cloud drop-size distributions in the troposphere and programmes for the study of equatorial waves in the atmosphere. Quantitative estimates of the vertical fluxes of momentum are needed to study the long and short period oscillations in the equatorial middle atmosphere. Measurements of such fluxes have been recently conducted by a combination of the MST radar, high-altitude balloons and sounding rockets. The data are needed

for studying the propagation of Kelvin (long period) and Rossby gravity (short period) waves.

Considering the recent developments in radar meteorology, a precipitation sensing radar installed on an Earth orbiting satellite is likely in the near future. The properties of waves emanating from the satellite and the radar will be one of the main problems for study in such a venture.

Computer Simulation and Mathematical Models

Numerical Weather Prediction (NWP) is based on a model of the atmosphere which is integrated in small time-steps. This was started by the IMD during the early 1960s with a third generation computer. Today, there are three centres where NWP is in operation; at the Indian Meteorological Department, the NCMRWF, Delhi, and IITM in Pune.

A Limited Area Model is used by the IMD, while NCMRWF uses a global model. The outputs from the IMD Model are largely oriented for meeting the requirements of civil aviation at the principal airports in India. On the other hand, the outputs from the NCMRWF are oriented for meeting the requirements of agriculture. They place the greatest emphasis on rainfall forecasts for 3 to 5 days duration. The work at the IITM at Pune is also research oriented. Work in this area had started with a third-generation computer but today the latest CRAY Computer is in operation at NCMRWF.

The major areas of uncertainty, on which research is in progress, are summarized below

Initial Conditions: The mathematical equations that predict atmospheric motion are very sensitive to the initial conditions with which the integration is commenced. Even very small changes in the initial conditions could lead to wide variations in the final output. Consequently, the best initial conditions are determined by using variational principles. Experimental forecasts are first made for small intervals of time, with an ensemble of initial conditions that differ only slightly from each other. The one that minimises the error between the observed and predicted values of the relevant variables are then selected as the best initial conditions. This process is referred to as the initialization of the prediction model.

Parameterisation of Clouds and Aerosols.

The NCMRWF Model uses a scheme that was first introduced in 1947 by Arakalwa and Schubert, with a few modifications. The scheme is based on (a) the release of thermodynamic energy and (b) changes in the water content of clouds. The model's specification of clouds changes with different scales of motion. In addition, a cloudy atmosphere is a multi-phase system. The aerosols and the liquid cloud, and the interactions between the two for different scales of motion have not yet been quantified. These could be important for studies on climate variability.

The Planetary Boundary Layer (PBL)

This is the region above the earth's surface, of approximately 1-km depth, where the effects of friction and heat flux from the ground are predominant. Uncertainties arise because it is difficult to quantify the ground features, especially in the vicinity of mountains.

The motion within a boundary layer is turbulent. The balance between the production and dissipation of the kinetic energy of turbulent motion has been recently worked out, although different views exist on how to quantify the dissipation function.

For including the boundary layer in a model, the turbulent fluxes are correlated to the gradients of the mean motion to the eddy diffusivities. A recent experiment compared the outputs from the NCMRWF Model by two different formulations of eddy diffusivity. In the first experiment, the conventional form of eddy diffusivity was used with an empirical dependence on atmospheric stability, while the second experiment employed a

correction factor for large scale eddy stress. It was observed that the latter approach yielded better results.

Radiative Effects

At present, the models developed by (a) the Geophysical Fluid Dynamics Laboratory and (b) the NASA / Goddard Space Centre in USA are adopted to quantify the impact of radiation. These models consider the absorption by each line of the electromagnetic spectrum. This has the advantage of considering the wavelength separation of direct solar radiation and the long wave terrestrial radiation. Of course, the major difficulty here is the problem of quantifying the role of clouds. As the temperature profile of the atmosphere and the distribution of clouds change with time, the radiative fluxes need to be calculated at different atmospheric levels and at frequent intervals of time. For long wave terrestrial radiation, the absorption at different wavelengths is complicated. Consequently, a line by line integration yields the best results.

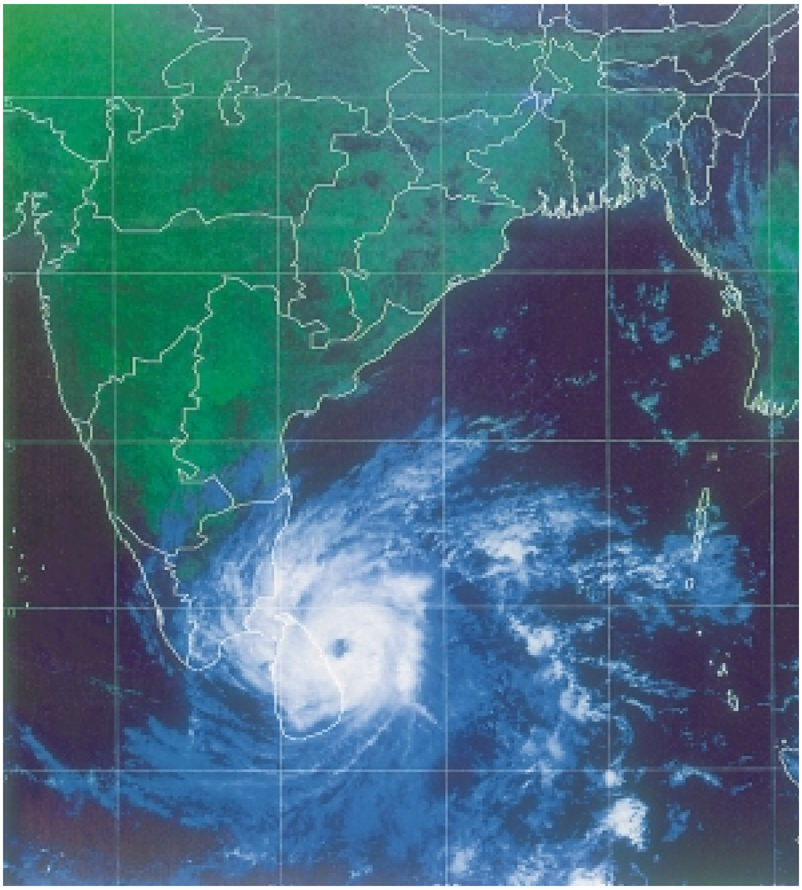


Photo: IMD and NCMRWF, New Delhi

A peep into the eye of the storm.

Walker Cells in a Steady Monsoon: A Walker Cell is an east-west oriented pattern of wind circulation in which the ascending limb of the cell is at its eastern end and the descending limb is located at the western end. The cell is named after Sir Gilbert . An early study of the monsoon in the 1960s had revealed a Walker cell type of circulation between the eastern and western parts of northern India during the summer monsoon months. Ascending motion over northeast India implies cooling because the air moves from higher to lower pressure. Consequently, to maintain a steady monsoon we need a warming mechanism to balance the cooling. This could be produced by the latent heat of condensation associated with the heavy rainfall of the summer monsoon. By the same reasoning, descending motion over northwest India, especially over Rajasthan, would imply a cooling mechanism to balance the warming due to descending air. The view has been put forward that the required cooling could be provided by the heavy dust load of the atmosphere over the semi-arid regions of Rajasthan. The required cooling due to scattering of light is about 1.6°C/day. There are a few uncertainties in this picture, because a steady monsoon is difficult to come by Reid Bryson, from the University of Wisconsin in the U.S.A., had brought a team of scientists to make actual measurements of cooling rates from an aircraft. Their observations showed results that were fairly close to the cooling rates prescribed by theory. More observations of this nature are needed in future because they could throw light on the causes of desertification over Rajasthan.

Oceanic Circulations: Tropical Cyclones

The advent of weather satellites and coastal radars have greatly improved our ability to detect and trace the path of cyclones in the Bay of Bengal and the Arabian Sea. Cyclones are more frequently observed in the post-monsoon months of winter. Next to earthquakes, tropical cyclones are the worst natural hazards in our country. However, improvements in our warning systems over the last fifty years has brought about a declining trend in the number of casualties, albeit with some exceptions, such as the Orissa Cyclone of 1999. The principal prediction problems in this field are: (i)prediction of formation and the path of cyclones, especially their recurvature near the coast; (ii) sudden changes in the intensity of cyclones, and (iii)Storm surges.

A scheme devised by U.S. scientist Dvorak in 1975 is used to classify cyclones according to their intensity. The classification is based on the characteristics of cyclones as seen on satellite imageries; especially on the enhanced infrared imageries. They provide an indication of the future movement of the cyclone. This is possible for intense cyclones whose intensity exceeds a threshold value. Similarly, another scientist from the IMD has pointed out that an increase in the surge of convective clouds is often the precursor of a cyclone in the Bay of Bengal. Another feature of a cyclone is multiple eye formation. The mechanism for multiple eye formation is not yet clearly understood. It is believed that the maximum angular momentum of winds rotating round a cyclone is often not reached at a single value of the radial distance from the cyclone centre. This could lead to the formation of two or more eye walls. The formation of multiple convective rings has been utilized by scientists from the Centre for Atmospheric Sciences at the IIT in New Delhi to suggest an interaction between two eye walls which could influence the path of a cyclone. It has been observed that low values of the Outgoing Longwave Radiation (OLR) are associated with the formation of cyclones because of an increase in cloudiness. This provides an indication for the formation of cyclones.

Considerable progress has been achieved by Indian scientists in designing prediction models for forecasting the amplitude of storm surges. This is a sudden rise in the sea level when a cyclone hits the coast. Monograms, prepared by different scientists, are now available to predict the surge amplitude from the observed features of a cyclone. Two of the unsolved problems in this area are (i) interactions between a surge and the tidal elevations, and (ii) the interactions between a surge and river discharges. These problems involve nonlinear mathematics, but research has made a beginning by expanding the dependent variables in terms of a small parameter.

Rainfall Variability and Ocean Atmosphere Interactions

Indian meteorologists have often experienced periodic changes in the rainfall generated by the summer monsoon. The reasons for such variations are still not clear. To improve our understanding of the role of oceans in causing such variations, a number of scientific expeditions have been arranged in the past two decades.

Two major expeditions were arranged in 1977 and 1979. The expedition of 1979, the larger of the two, was named the Monsoon Experiment (MONEX). It was a part of the Global Atmospheric Research Programme (GARP), that was organized, jointly, by the WMO and the International Council for Science (ICSU). MONEX revealed many features, that were not realized earlier. By tracking the path of constant level balloons, for example, it was possible to see that the origin of the monsoon winds lay in the southern hemisphere.

An Indian Ocean Experiment (INDOEX) was organized during the winter of 1998, with the aim of determining the radiative forcing by aerosols. An interesting result showed high values (40 w/m^2) of radiative cooling by aerosols, which had not

been observed before.

Yet another recent experiment was the Bay of Bengal Monsoon Experiment (BOBMEX) in 1999. This experiment was part of the Indian Climate Research Programme (ICRP), with a main focus on the marine boundary layer over the southern Bay of Bengal. The experiment collected valuable data on convection and its associated energy transformation in the atmosphere, somewhat similar to the observations made over a warm pool of water over the west Pacific Ocean. A second experiment similar to BOBMEX is now being planned for the Arabian Sea to study convective processes over a warm pool of water on the southern sector of the Arabian Sea. It could yield useful information for predicting the onset of the summer monsoon.

ENSO Linked Rainfall Variability

ENSO stands for combination of the El Nino (EN) and the Southern Oscillation (SO). The Southern Oscillation was discovered by Sir Gilbert Walker who found that the inter-annual fluctuations over the Indian and Pacific Oceans were inversely related to each other. Thus, when high pressure exists over the Pacific, it was low over the Indian Ocean, and *vice versa*. And, as high (low) pressures imply low (high) rainfall, the Southern Oscillation represents a rainfall oscillation. *El Nino*, is a Spanish word which means a male child. It is used in meteorology to denote, a sudden spread of warm waters off the coast of Peru towards the east. This is referred to as an ENSO event. The summer monsoon rains are unusually deficient in the ENSO years, although the relation between an ENSO event and poor monsoon rains is not established.

The link between rainfall over the equatorial regions of the Pacific and Indian Oceans is now a topic of considerable research interest. Scientists in China attribute this to similarity in air sea interactions between the two oceans. But, interestingly, experiments with ocean atmosphere coupled models suggest that an increase in sea surface temperatures (SST), such as an ENSO event, could induce oscillations in another basin. The models start with two adjoining oceanic basins separated by a narrow strip of land. This mimics the Pacific and Indian Oceans with a land strip dividing the two. The results suggest that warming in one ocean will induce oscillations over the other.

Global Warming and Rainfall Variability

The global mean temperature records show a general warming trend, of about 0.3 to 0.6°C in the last hundred years. (IPCC, WMO, 1992). Opinions differ, but it is difficult to assess whether this constitutes a signal in the time series, or whether it is a part of the natural variability of the temperature time series.

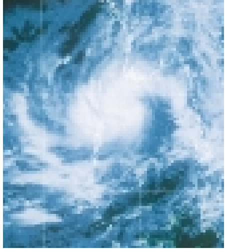
This is particularly so because temperature and rainfall appear to move in opposite directions. In China, for example, the summer monsoon rain became weak in the 1920s when there was rapid global warming. A similar situation prevails over India. Thus, there has been a rapid increase in the combined land, air and sea temperature from 1970 onwards, but the trend observed in summer monsoon rains has been one of decrease. Opinions are also divided on whether there has been any significant increase or decrease in the number of depressions or cyclones from 1970 onwards. There are also uncertainties regarding the models that predict global warming because of the negative feedback from clouds.

Despite the difficulties of climate predictions, attempts are being made to predict the quantum of rainfall during the monsoon season. This is based on a statistical regression equation which links the predictand (monsoon rains) with several predictors. The prediction used to be for the whole country, but is now made for separate regions where the rainfall pattern is homogeneous. This technique needs improvement for it is not clear, for example, how much of the variance of rainfall is explained by the regression model, or whether the predictors are

independent of each other. Unfortunately, due to the wide limits of tolerance, predictions for a normal monsoon are made year after year. This does not agree with facts. But, an interesting possibility has recently emerged. It has been suggested that 'breaks' in monsoon rains could be predicted by improved regression equations.

Snow Cover Influence on Monsoon Rains

The interesting possibility of a link between the Himalayan snow cover and summer monsoon rains is a research project of much interest to Indian meteorologists. Hitherto, the project was hampered by lack of data, but this position has improved considerably after the advent of satellites and improvements in radar technology. The recent developments in this field have been described in a book, *The Himalayan Environment*, brought out by scientists from the Centre for Atmospheric Sciences at the IIT, New Delhi. The principal impact of snow is linked with its high albedo, or reflection power for solar radiation. This provides a negative feedback which could be of the order of 15 walts/m^2, to the earth's radiation budget. The presence of clouds could increase the negative feedback. And, interestingly, this is of the same order as the negative feedback from aerosols. These features need to be considered in the design of mathematical models to simulate the airflow over the Himalayas.



CHAPTER XIII

INDIA AND THE GLOBAL CLIMATE CHANGE

At the outset, it is important to point out that global change is more than climate change and concerns the functioning of the entire earth system which consists of solid earth, oceans, cryosphere and atmosphere. The emphasis now is on the changing earth in all its components. This write-up deals with only atmospheric science, the other areas are covered elsewhere.

THE "UPPER ATMOSPHERE" BY S.K. MITRA

Global change science began in India with the publication of the book *The Upper Atmosphere* by S.K. Mitra in 1947. He considered, for the first time, the atmospheric environment as a whole-neutral and ionized - its thermal structure and distribution of constituents, its motions, the interaction of the solar radiation and the particle streams from the sun with these constituents. He also considered the atmosphere from the surface to the fringe of the upper atmosphere.

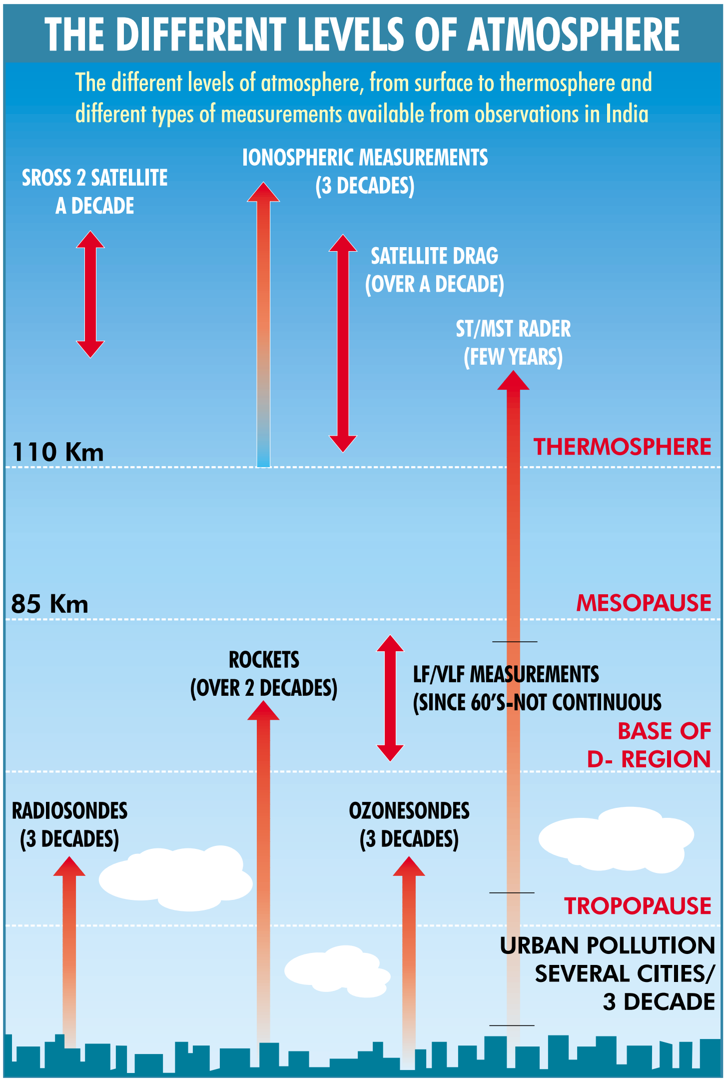
THE INTERNATIONAL GEOPHYSICAL YEAR

The next major milestone was the International Geophysical Year (IGY) which was started on July 1, 1957, and continued in an extended capacity through IGC (International Geophysical Cooperation) till December 31, 1959. It marked a watershed in the Indian scientific research on the study of our planet and the sun. Coordinated national efforts under the framework of controlled intercomparison under specified conditions were perhaps introduced for the first time. It brought a revolution in Indian science in several areas: in ionosphere, in cosmic rays, in geomagnetism, in solar physics, in meteorology and in several related areas of earth sciences. This was also the occasion for first organized entry of Indian science in the inter-national arena. New information emerged on the role of solar radiation -- both electro-magnetic and particles on the earth's atmosphere.

Of direct interest or relevance to the present scenario of global change was the preparation of the Standard Atmosphere for Tropics developed as early as 1979. This included a *reverse lapse rate* (i.e. increase in temperature) above the tropopause rather than an isothermal atmospheric stratosphere. The considerably higher tropopause level observed was also included.

The important roles played by minor species for climatic changes had not yet been recognized. However, three particular minor species were even then considered to be of significance: water vapour, ozone and carbon dioxide.

For ozone the question of large scale global changes through human activities had not yet been brought up. Dobson spectrophotometers provided values of total ozone and this could be directly used: profiles could be and were indeed derived from Umkehr method. Some results even at that time caused surprise. One was the existence of low ozone content at equatorial latitudes -- some of us called it the *Natural Ozone Hole* at latitudes where production is the largest. Large day-to-day fluctuations in ozone content were noticed; the



largest fluctuations were in January to March believed to be associated with westerly disturbances. Another interesting result was the low ozone values for the Indian stations as compared to Japanese stations with nearly the same latitudes.

The third minor constituent on which some attention was given during the IGY was carbon dioxide (CO_2). It was already known that the atmospheric CO_2 content had been continually rising due to increasing use of fossil fuels (a problem that is now taken to be one of the most serious threats to climate stability). The IGY-time atmosphere contained approximately 315 ppm of CO_2 with an annual increase of about 0.7 ppm although fossil fuel combustion added annually 1.6 ppm of CO_2.

Human Activities and Space Environment

In the 1970's, there was already increasing global concern about the nature and extent of human effects on our environment. The controversy centred around: (a) the CO_2 problem and (b) the ozone problem. While these two were the main centres of public interest, it was pointed out that there are other possible sources of environmental hazard. Examples are the inadvertent heating of the ionospehre by high power HF radio transmitters; ionospheric holes produced by spacecrafts effluents, and ionospheric modification by the then proposed Solar Power Satellite Launch Vehicles (SSLVs).

In a monograph brought out in 1982 (by the National Physical Laboratory, New Delhi) the question of human activities was reflected in a more comprehensive way, covering the entire atmospheric environment, the canvas extending from the surface to about 1000 km. Three broad levels were considered:

a The Tropospheric Level where the principal anthropogenic sources are carbon dioxide and aerosols (the role of CH_4 and N_2O were to be added later),

b The Stratospheric Level where the principal problem was the question of ozone depletion (the ozone hole was yet to be discovered), and

c The Ionospheric Level where high power transmitters and spacecraft effluents inadvertently modify the ionosphere.

Important points noted are the following:

i In the tropical areas the tropopause level is higher (at Thiruvananthapuram around 16 km) in contrast with level of about 8 km at mid-latitudes.

ii In the troposphere there is complete mixing. Consequently, chemically inactive constituents will be completely mixed in the atmosphere and are eventually washed out by rain. Photo-

dissociation is effective in most cases only when the injected material is lifted up in the stratosphere, as with CFMs -- the most important man-made ozone depleting source.

iii Ozone lifetime is a few days near the ground, a few weeks in the stratosphere, but a few hours or fraction of hours at heights above 60 km. Thus short term changes in ozone at lower heights essentially local and a result of dynamics.

Several important points, relevant to India emerged. For the hypsithermal period (4000-8000 years ago), when the world as a whole was warmer by about 3°C, much of India, especially southern part in an estimate by Kellogg (1979) was wetter. Analysis for the last 50 years, for which the Northern Hemispheric warming averaged about 50°C Kellogg's prediction was of cooling over Japan and much of India.

Reference ozone atmosphere over India as well as reference profiles of minor constituents were formulated. It was noted that Indians (whether in India or domiciled in other parts of Asia and in Africa) have a very low melanomic rate (only about 1/10th of the Caucasians).

A totally new perspective was the recognition of the role that ions could play not only in the region of the middle and the upper Ionosphere, but even in the troposphere and stratosphere. This early work of extending investigations of effects of human activities to the middle atmosphere has been continued, in particular by Indian Institute of Tropical Meteorology (Pune) and the National Physical Laboratory, leading on to joint international efforts (as a part of IUGG) on changes in middle and upper atmosphere.

On the thermal structure model calculations showed cooling in the upper stratosphere, mesosphere and thermosphere. Daily radiosonde data for the troposphere and stratosphere and temperature profiles determined from weekly rocket flights from Thumba to heights of 70 km revealed that warming in the lower atmosphere has taken place over India from 1963 to 1997, whereas the stratosphere and lower mesosphere have undergone cooling. Modeling suggests that other changes may also have occurred. An increase in water vapour and decrease in NO in the mesosphere and thermosphere is most probable. Ion composition is also likely to change in the middle atmosphere with implications for a number of atmospheric processes. The models also suggest the mesosphere may become wetter and cooler.

Serious studies to examine global change signals in the middle and upper atmosphere require availability of consistent and continuous series of data on temperature, density and composition (neutral atmosphere) and of ion density and ion composition (for Ionosphere). Fortunately, over the five decades covered under this article, an exhaustive series of data have become available.

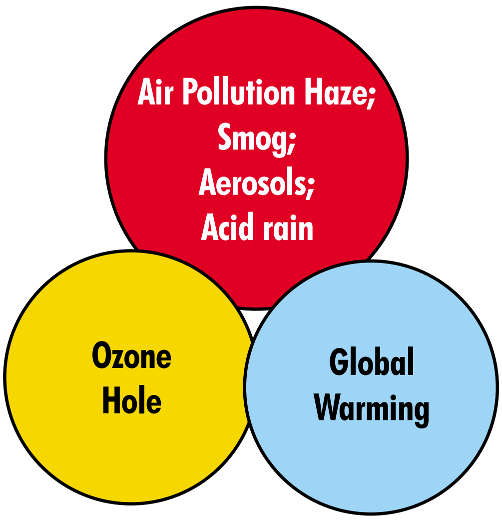
The Indian Middle Atmosphere Programme

The next major event was the undertaking in India of an extensive programme covering the atmospheric region from surface to 120 km as a part of the International Middle Atmosphere Programme.

It was the largest programme undertaken in India under an International umbrella after the first major effort in IGY. Indian interest in this programme arose from several excellent facilities that existed and the interest regarding the role of the middle atmosphere in monsoon circulation and atmospheric chemistry. Some special aspects are outlined below :

- Accessibility to 3 rocket ranges: Thumba (90°N), SHAR (140°N) and Balasore (21°N).
- Availability of a national balloon launching facility at Hyderabad.
- A dense network of radiosonde stations operated by the India Meteorology Department (IMD) and its continuing operation of key experiments: (a) Ozone measurements with Dobson spectrophotometer and balloon-borne sensors, and (b) atmospheric turbidity measurements in 10 stations.

A NEW SCENARIO IN WHICH OZONE CHANGES, URBAN POLLUTION & GLOBAL WARMING ARE INTERLINKED



- Development of new facilities.
  Meteor Radar at Thumba
  Lidar at Thumba
  Laser heterodyning facilities at Delhi.

The Indian Programme that was organized involved the participation of some 200 scientists operating in stations spread over India with direct involvement of seven science agencies, several National Research Institutions and 11 Universities. A major fallout was the undertaking of an MST Radar as a national facility.

A major aim was to evolve a first order reference middle atmosphere over India. This was achieved.

Regarding the neutral middle atmosphere, a revised International Tropical Reference Atmosphere up to 80 km was proposed and later extended to 1000 km. For minor species, constituents examined included: ozone (fairly extensive), water vapour, methane, N_2O, CFCS (limited). On minor constituents, measurements of ozone were the most comprehensive and involved essentially all known techniques excepting satellite-borne measurements.

Some interesting findings emerged:

i the larger-than-predicted night/day ratios in ozone at all heights above 27km; night values being higher up to 60 km,

ii height-dependence of changes in ozone during a solar eclipse (16 February, 1980): decrease below 25 km, no perceptible changes between 25 and 35 km, and increase above 35 km,

iii the higher altitude of ozone peak concentration at Thiruvananthapuram (27 km) than in Hyderabad (24 km),

iv Anomalies associated with cloud cover or passing weather disturbances: bulges of increased values in the range of 800 to 500 mb and fluctuation patterns in ozone profiles with depleted values in 500-100 mb range,

v Large depletion in ozone between 10-22 km in the Indian Antarctic station *Dakshin Gangotri* (70°S, 11°E), located in the fringe of the 'Containment Vessel'.

In one of the rocket flights there was evidence of increase in ozone around 5 km during a storm with lightning discharges.

For other species ($CFCl_3$, CF_2Cl_2, CCl_2FCClF_2, $CBrC1F_2$) there was only one set of balloon-borne measurements conducted over Hyderabad in 1985 with a cryogenic gas sampling arrangement as a joint effort of Max Planck Institute for Aeronomie at Lindau and the Physical Research Laboratory at Ahmedabad. It was noted that the decrease in concentration started at an altitude higher than in mid-latitudes and also the rate of decrease was slower.

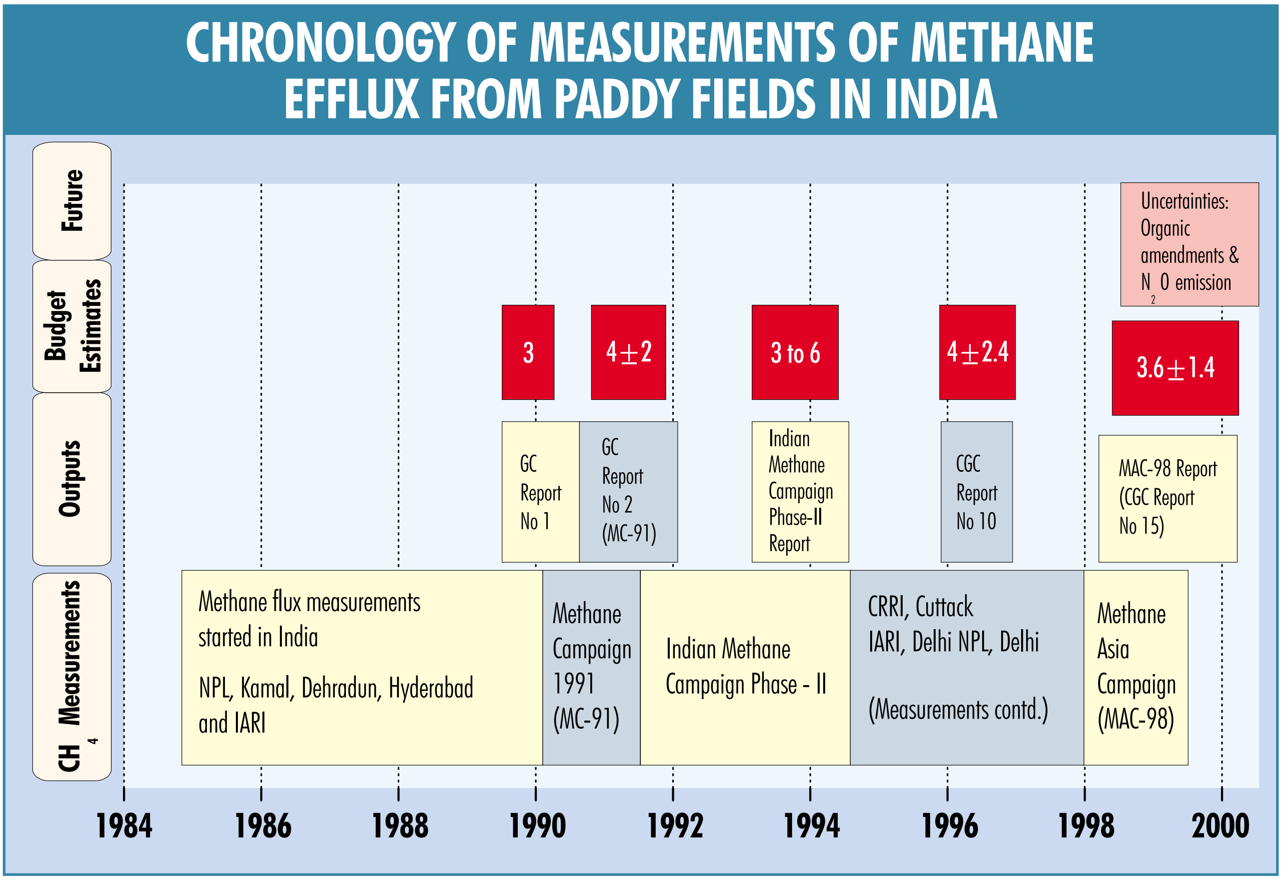
Methane Emission from Paddy Fields: An Exciting Study

In the early 90s just before the First Assessment Report of the Intergovernmental Panel for Climate Change was to be released, a new effort was mounted that changed radically the view of methane emission from paddy fields, from India in particular but also globally.

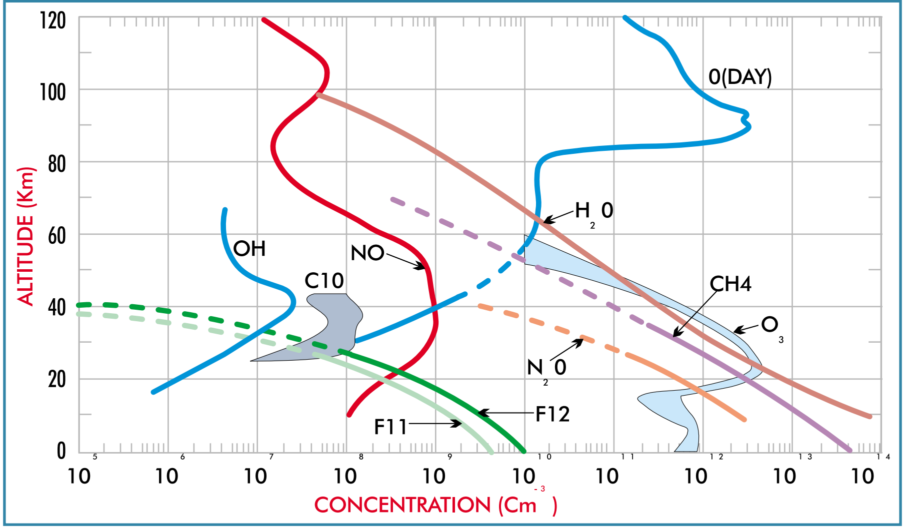
Earlier, in the absence of adequate CH_4 emission data from India, the US-EPA estimate for India was 37.8 tg CH_4 per year. This was based on data collected from experimental paddy fields in

Europe and America and extrapolated for the Indian region. However, measurements undertaken by National Physical Laboratory on CH_4 afflux, conducted later, yielded a value of 3 tg CH_4 per year which was based on a few actual field measurements made during the period 1985 to 1990 at selected rice growing regions in the country. This budget was not based on measurements carried out over a full cropping season and did not reflect fully the CH_4 flux from major rice growing regions in the country. Therefore, to have a more reliable budget estimate a CH_4 measurement campaign was launched in 1991 to cover the gap. During this campaign care was taken to generate internationally compatible data which were better calibrated nationally as well as internationally. Also stress was given on measurements over the whole cropping period from all water logged paddy areas in the country (as these were expected to emit maximum CH_4). It was seen that the rain fed waterlogged and deep/semi deep category of paddy fields which together constitute 41% of the total harvested area are a source of 94% of the total CH_4 emitted from all harvested water regimes whereas in comparison the upland and irrigated areas (53% of total harvested area) have negligible contribution. Maximum CH_4 budget estimated was around 6 tg/yr and the minimum around 2.5 tg/yr from the Indian paddy fields. The mean was around 4.0 tg/yr -about 1/10th of the value suggested by US-EPA.

The lower value for India indicated that the global value may also be considerably lower than the estimated around 100 tg CH_4 yr^{-1}. Meanwhile measurements in other countries in Asia (Philippines, China, Thailand, Vietnam etc.) also indicated lower values. NPL and ICAR continued the measurements to reduce uncertainties, identify key factors controlling the emissions and the role of



PROFILES OF IMPORTANT MINOR SPECIES OBTAINED DURING IMAP



energy and industry for India, 126% for Bangladesh, 62% for Pakistan and 325% for Sri Lanka. For the subcontinent as a whole the ratio is 55 %. For energy production 65% of CO_2 emission from fossil fuels come from coal in the case of India and 70% in case of China. The quantities consumed have increased by a factor of 4.5 for India from 1970 to 1997 and by a factor of 2.6 in case of China from 1973 to 1996.

organic amendments and nature of cultivars. It was primarily the Indian efforts that led to the revision of IPCC methodology in 1996.

New International Efforts: ALGAS and INDOEX

A new look on the changing atmosphere became possible from several international efforts organized recently. These include: Indian Ocean Experiment (INDOEX) and ALGAS.

ALGAS was a 2-year programme covering 12 countries in the Asian region -- Bangladesh, China, India, Indonesia, Republic of Korea, Mongolia, Myanmar, Pakistan, Philippines, Thailand and Vietnam. These represent 51% of the global population. The objective was to generate an inventory of long-lived greenhouse gases for these 11 countries for the year 1990 , following internationally laid guidelines, provide baseline projections for 2020, identify mitigation strategies and define least cost options. Although the total emission from this region is only 3% of the global emission, its growth rate is high -- 6% for India, 8% for Bangladesh and 10 % for Pakistan. Unlike other regions emissions from agricultural sources can dominate. Emissions from agricultural sources in terms of CO_2 equivalent is 50 % of emissions from

ALGAS concentrated mainly on greenhouse gases CO_2, CH_4, N_2O because of the requirements of UNFCCC but nevertheless also provided data on CO and NOx from some sectors. No estimates were made of aerosols.

INDOEX, on the other hand, concentrated primarily on aerosols and the resultant radiative forcing covering the western part of the ALGAS region. In addition there were measurements also of CO, NOx and ozone. Thus information provided by the two are in some senses complementary.

INDOEX was an extensive international programme, involving several hundred scientists from the USA, Europe, India and the island countries -- Maldives, Mauritius and Reunion. Aerosol cooling or heating (from aerosols such as sulphates, soot, organic carbon, mineral dust) has a large element of uncertainty (especially in the indirect component) and complicates our understanding of the combined impact of increasing GHGs and aerosols. In addition, in the developing South, East and South East Asia, aerosol emissions from a variety of sources (fossil fuel, biomass burning, etc.) are increasing at a rate faster than those of greenhouse gases.

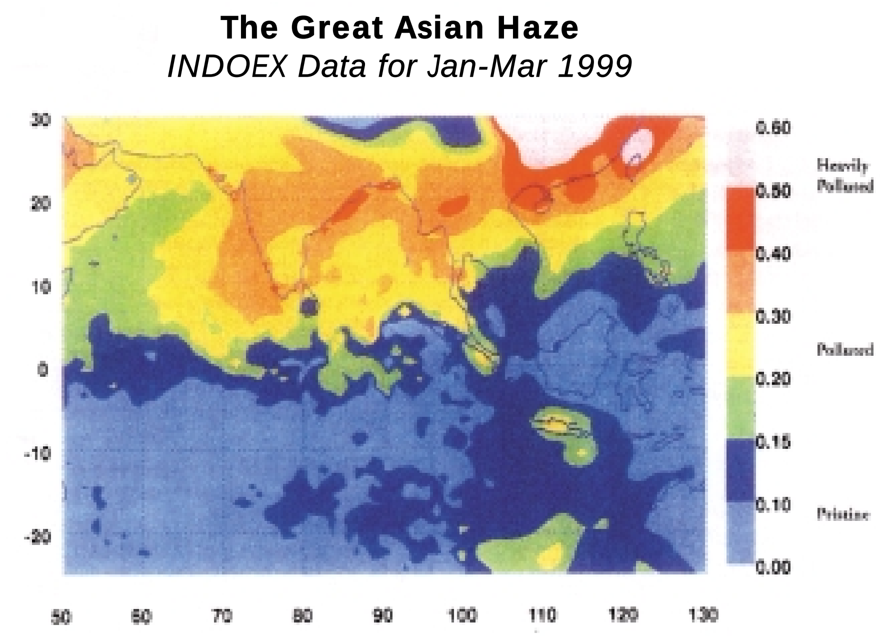
INDOEX addressed this question by focussing on a region in the Arabian Sea and the Indian Ocean

during January to March -- at a time when the 'polluted' air from the Indian subcontinent and the pristine air masses from southern Indian Ocean meet over the tropical Indian Ocean at latitudes between 0° and 15°S.

Indian contributions were critical -- through own experimental arrangements in groundbased stations (Delhi, Mount Abu, Pune, Ahmedabad, Thiruvananthapuram, Vishakapatnam, Mysore, Minicoy, and Mauritius), on board *R.V. Sagar Kanya* and the use of INSAT and IRS P3 satellites. In addition, the Universities of Goa and Dharwar collaborated with French efforts in launching constant pressure balloons from Goa (totalling 19 flights during IFB 1999), and groundbased observations on aerosols and ozone in Dharwar and Goa. MST Radar operating in Gadanki alongwith a Lidar and LAWP was also operated in a campaign mode. Three lidars were available at Mount Abu, Pune and Thiruvananthapuram. There was also a special campaign on biomass burning of shifting cultivation in one of the hilly northern parts of Andhra Pradesh -- Eastern Ghat. A specially set-up group on weather forecasting provided daily weather forecasts and trajectory information that proved valuable for the entire operation. Experiments on board *Sagar Kanya* were made in four consecutive years 1996 –1999, with cruise paths, covering the region of interest and providing an insight into the variability in ocean and atmospheric parameters .

When observed data were integrated with data from satellites and climate models, an extensive haze layer was discovered -- called the 'Great Asian Haze'. A part of the aerosol consisted of black carbon (soot), arising from incomplete combustion of biomass and fossil fuels. These are absorbing aerosols and reduce significantly the solar energy reaching the earth's surface and the oceans.

INDOEX coverage was limited to the Indian subcontinent and the surrounding oceans and was also focussed on the period January to March when the wind is predominantly southwards. Transport to long distances of pollutant plume originating from the Indian landmass brings in a new parameter : the question of transboundary pollutant transport. INDOEX data suggest that soot particles, sometimes lodged in submicron sulphate and organic aerosols, travel long distances. This is, however, not unique to the Indian or the Asian region. African dust storms have been seen to spread over the Atlantic to the Eastern coast of the United States. Asian pollutants have been observed to reach northwestern USA across the Pacific Ocean. Plumes generated in the USA and Europe are also known to travel far. Haze cloud originating from



The regional map of aerosol column amount. The valves over ocean are retrieved from satellite data and over land are estimated using a 3-diamensional model.

Indonesian forest fires have caused health concerns in the neighboring countries, and have caused the creation of a special study group in East Asia.

What is special, however, is (a) the absorbing nature of the haze cloud, arising from a large presence of black carbon, (b) relatively low values of tropospheric ozone even in the polluted region indicating that NOx concentrations in this region are still low, and (c) model calculations showing possible impact of such aerosol cloud in modifying ozone concentrations in distant regions (e.g. Europe) if the aerosol emissions continue to increase at the present rate. There is also possibility of reduction of NO limitation in future producing large-scale photochemical smog.

Impacts of Aerosol Loading

Changes in climate forcing are still not clear for a situation in which both scattering and absorption by aerosols are involved. INDOEX calculations indicate the possibility of a number of changes: reduction in daytime low cloud cover by 20% to 18% (decrease by 2%), suppression of precipitation from low clouds and reduction in evaporation from the oceans by about 6%. The aerosol heating induces a large dynamical response causing ITCC to move northwards, enhancing convective rainfall over the haze area and reducing precipitation over the Indonesian region. These are all very serious consequences, even though quantitatively approximate at this stage. It is clear that climate change scenarios developed only on the basis of changes in long -lived greenhouse gases can be misleading. It is thus strange that this critical factor continues to be outside the only international framework convention in position.

For countries like India, where food security is at the core of the development process, the effects arising from haze-induced reduction of sunlight is a new parameter that should now be added to previously examined efforts from changes in temperature and precipitation and CO_2 enrichment. The effect of such reduction is a decrease in agricultural yield of nearly the same magnitude. Although India is now comfortably placed in terms of food production, the projected requirement of substantial increase in yield (from around 2 t/ha to about 4 t/ha in the case of rice in about 20 years) will need a new strategy, given the growth rate currently below this requirement and the complex nature of different elements of global change. The strategy is to optimize the combined effects of these perturbations through selective mitigation efforts. A reduction in aerosol loading appears to be one such effort.

As mentioned earlier, aerosol-associated health hazard has already assumed critical state. World Bank estimates suggest over 80,000 deaths annually in India due to outdoor air pollution and a staggering number of 5,00,000 deaths for children below 5 years due to indoor pollution (3,00,000 deaths for children below 1 year). These deaths are the third in order after malnutrition and water-borne diseases. The most serious hazard is acute-respiratory infection (ARI) for children below 5 years. Risks include acute respiratory infection, chronic obstructive pulmonary diseases and cardiovascular diseases.

New Policy questions have emerged (some of relevance to the Kyoto Protocol). The presence of a huge sunlight-absorbing haze layer extending over some 10 million square kilometers over the Asian and the northern Indian Ocean region confirmed that urban air pollution (till now considered local)

Climate Forcing Pollutants

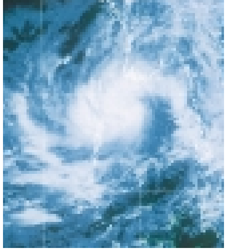
Protocol GHGs			Short lived Gases	Particulates
1.56 Wm^2	CO_2	1	O_2	• Cooling Aerosols
0.47 Wm^2	CH_4	21	CO	
0.14 Wm^2	N_2O HFC	310 140	NO_2 SO_2	• Heating Aerosols
Little now	SF_6 PFC	23,900 Large		(transport over long distances)
GLOBAL			LOCAL TO REGIONAL	
Decades and Centuries			Weeks and days	Days

Past 100 years T 0.3-0.6 Sea Level: 10.25 cm
Asia 1990: COs Equivalent 12% of World. Population over 50% of world

has continental and ocean basin scales. It has provided an interface between air quality and global warming and emphasized the incompleteness of the Kyoto Protocol where aerosols and ozone precursor gases are not included.

Two special aspects are only beginning to be recognized: one is that the pollutants are of three distinct categories : the long lived gases (CO_2 ,CH_4 , N_2O), the short lived gases (CO, NOx, SO_2) and the particulate materials of different sizes and composition including climatically important soot carbon (see Table). All these have been increasing very rapidly with growth rates of 4-6% in most cases, 3-5 times higher than in most industrialized countries. The emphasis, however, has been largely on the long-lived gases.

What is now emerging is a new scenario in which ozone changes, urban pollution and global warming are interlinked. New efforts in this direction are now being taken up.



CHAPTER XIV

VIGNETTES OF BIOLOGY

THE EARLY DAYS

India has built a vibrant tradition in research and teaching in various areas of modern biology. In the early days of the twentieth century, physicist Jagadis Chandra Bose initiated experiments in Kolkata on the electrophysiology of plants. One of the earliest schools in biochemistry (first in India and second biochemistry department in the world), was established at the Indian Institute of Science, Bangalore, over 80 years ago and it continues to be one of the top research institutions in the world. Biological research in the early decades (1920-1955) was strong in the areas of enzymology, vitamins and cofactors, nutrition and organic chemistry of natural products. Some of the well-known names are: J.C. Bose in plant physiology; P.S. Sarma, who led a dynamic team in enzymology and intermediary metabolism; H.B. Cama in nutritional biochemistry; Birbal Sahni in palaeobotany; B.C. Guha in vitamins and cofactors; C.S. Vaidyanathan in plant enzymes; A.R. Gopal-Iyengar in radiation biology; B.P. Pal in agriculture; P. Maheshwari in plant embryology; Shambhu Nath De in microbiology (he was the first to describe the endotoxin of *Vibrio cholerae)*; N.N. Dasgupta in electron microscopy; and R.N. Chopra in pharmacology.

Each of them built an active school and research group so that when India became independent in 1947 and began rapidly developing its education and research institutions, it had a good number of well-trained researchers capable of creating centres of excellence. It was around this time too that notable advances were being made in the world in the areas of genetics, microbiology and biophysics. The new field of molecular biology was emerging. Thanks to the academic and research background that it already had instituted, it became possible for India to spawn research teams that could participate and contribute in these newly emerging areas of biology.

The field of human genetics is vibrant in India, and owes its strength historically to the efforts of J.B.S. Haldane who put together a team of doctors and statisticians in analyzing the prevalence of genetic disorders, unusual traits and related features in India -- *a living genetics laboratory*, as he called it. One of his students, P.M. Khan, became well-known for his comprehensive and analytical research into the biology of colorectal cancer. A welcome consequence of Haldane's efforts was to bring together genetics and statistics and establish a research group in anthropology and human genetics at the Indian Statistical Institute, Kolkata.

THE MODERN ERA

A similar and equally fruitful effort has been the establishment of biology divisions at the Atomic Energy Establishment in Mumbai, and its sibling, the Tata Institute of Fundamental Research (TIFR) at Mumbai about 40 years ago. This group pioneered research into the genetics of the fruitfly, *Drosophila melanogaster*. While classical cytogenetics was an active and useful field practised by several groups at Kolkata, Varanasi, Hyderabad, and Chennai, the group at TIFR helped usher in the fields

of molecular biology, electrophysiology and mutation analysis into genetics. On a similar line were the efforts of medical researchers in bringing together the fields of nutrition, biochemistry and physiology.

Around the same time G.N. Ramachandran, himself a student of C.V. Raman, ushered in the field of molecular biophysics. This area attracted not only physical chemists, but physicists, mathematicians and computer scientists as well. To a major extent, the notable presence of Indian researchers currently in the area of bioinformatics on the one hand and in X-ray crystallography on the other, is an outcome of the 'Ramachandran effect'. In this sense, Ramachandran has been to biophysics what Haldane has been to genetics in India (see also chapter on Biophysics and Structural Biology).

Beginnings of New Biology

Biological research activities in India can broadly be classified under two heads-- the classicial and the modern. Classical biology largely refers to areas where tissues, organs, whole plants, and organisms are studied. It was pursued by compartmentalized, strictly discipline-bound scientists in botany, zoology, microbiology and so on. Modern biology is largely based on molecular and cellular techniques that cut across disciplinary boundaries and utilizes common tools and techniques, be it for the study of microorganisms, plants or animals. Classical biology or systems biology was already thriving in India around the 1950s, and was done effectively in a few universities and the national agricultural research institutes. Scholars trained in botany, zoology and agriculture were the major players here. Indeed some trail-blazing discoveries and developments were made in universities. It is not commonly known that the areas of protoplast fusion, anther culture and nucellus culture, as well as micropropagation using tissue culture of plants got its earliest start in India, notably in the Department of Botany at the University of Delhi (DU). Already by the late 1950s, micropropagation of a variety of plants was regularly achieved in the laboratories there. At about the same time, plant geneticists realized the importance of hybrid seeds, mutants, selection breeding and the like. The Indian Council of Agricultural Research, which predates India's Independence , had established excellent field stations and research outlets at various places such as New Delhi and Coimbatore. Thus when the Mexican dwarf varieties of wheat were introduced to the world by Norman Borlaug, one of the earliest countries to take advantage of this was India. Based on a systems approach, involving hybrid seed selection and breeding, irrigation, use of appropriate fertilizers, post-harvest technologies and distribution of the produce, led to what is now recognized as the Green Revolution.

Modern biology as understood today had its origins in India around the 1970s. The country was fortunate in already having a cadre of scientists trained abroad in these areas. Several of them were front-ranking players in the development of many methods and in the significant discoveries made in enzymology, biopolymer structure and conformation, reverse transcription, molecular virology, ribosome structure, transcription and translation, cell culture techniques, biomolecular spectroscopy, computer methods and so on. It was roughly about the same time that the Department of Science and Technology (DST) initiated a facilitating mechanism called the National Biotechnology Board (NBTB). This Board played a proactive role in promoting specific methods and technologies, curricular programmes, research laboratories and funding research projects of individual scientists. Within a short time, NBTB matured into a full-fledged department of the government, called the Department of Biotechnology (DBT).

Biotechnology has earlier been used, in the classical sense, in India in improving livestock health and wealth. Selection breeding of chosen breeds of milch cattle, sheep, horses and other animals has been effective.

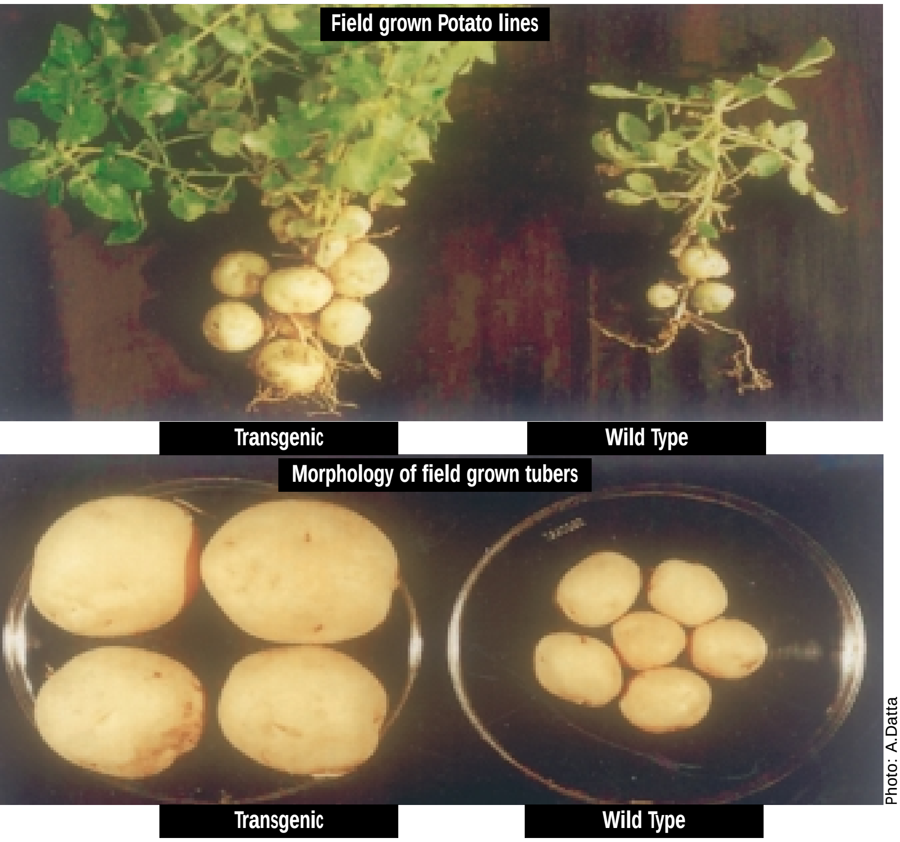
Plant Molecular Biology: Some Facets

The beginnings of plant molecular biology in India have been traced in a recent review article in *Current Science* (vol.80,2001). Only a few aspects are covered here.

Groups of scientists in Kolkata, Kalyani, New Delhi, Chennai and Bangalore have been pursuing plant biochemistry, physiology and molecular biology. The work of biochemists at IISc in the cloning of rice histone genes and their transcription was a turning point for molecular biology in India. Several groups began research in the border-line areas of hormone- and phytochrome- mediated stimulation of RNA synthesis and molecular biology of stress. The research on photosynthetic genes and their regulation has been carried out on *Vigna*, rice and *Arabidopsis*. The involvement of C^{++} and protein phosphorylation has been demonstrated in regulation of plastid gene expression. New stress proteins that are critical for overcoming stress to high temperature, salinity and drought have been discovered in rice. Interestingly, one heat shock protein (hsp) which is 110 kd is homologous with a protein of yeast, indicating the unusual conservation of the machinery to overcome stress. A number of Ca^{++} activated protein kinases have been identified. It is observed that the influx of Ca^{++} is regulated by phytochromes. Genes like nitrate reductase and PsaF are regulated by phytochrome and this involves phosphoinositide cycle. Besides its role in photosynthesis, light is indispensable for growth, elongation, maturation, flowering, reproduction and other morphogenetic phenomena. Scientists at JNU and ICGEB have been studying the preception of light signalling and gene expression, specially with reference to the photosensor, phytochrome. Several photomorphogenic mutants of *Arabidopsis* have been isolated and characterized at DU. One of these mutants, JK 224 (redesignated later as nph 1), has paved the way for molecular cloning of the hitherto unknown blue light receptor, phototropin, that regulates phototropic response in plants. Recently, genes for NPH1 and phytochromes have also been cloned and sequenced from rice and wheat, respectively. Another class of mutants display constitutive photomorphogenesis, including depression of gene expression, even in total darkness and flower precociously.

At Jamia Millia, the codA gene from Arthobacter globiformis has been used for transforming *Brassica juncea* cv Pusa jaikisan to enable the latter to synthesize glycinebetaine to enhance its salt and drought tolerance property. Improvement in nutritive value of crop plants, especially amino acid composition, has been a major long-term goal of plant breeding programmes. Towards this end, the cloning of seed albumin gene was initally reported from *Amaranthus hypochondriacus* at JNU. The Am A1 protein is non-allergenic in nature, rich in all essential amino acids and corresponds well with the WHO standards for optimum human nutrition. To improve the nutritional value of potato, the AmA1 coding sequence was successfully introduced and expressed in a tuber-specific and constitutive manner. A striking increase in growth and production of tubers was seen in transgenic populations and also of total protein content with a marked increase in most essential amino acids. This is the first report of a seed albumin gene with a well-balanced amino acid composition being used as a donor protein to develop transgenic plants.Of special interest is the work transferring oxalate decarboxylase gene from a fungus to tomato to improve the nutritional quality.

Engineering Bt genes in rice has been reported from Bose Institute, Kolkata and in brinjal, tomato, cabbage and rice from IARI. Plant geneticists of DU have used both conventional breeding and biotechnological approaches for crop improvement. In mustard the technology of producing hybrid seeds through the use of transgenics containing barnase and bastar genes has been developed. Barnase lines have been developed and are being diversified in the appropriate cultivars. Restorers



Designer potato for better yield and nutrition.

- ***AmA1 protein is non-allergenic***
- ***Expression of AmA1 leads to:***

  More than two-fold increase in tuber number,
  3-3.5 fold increase in tuber yield in terms of fresh weight, and
  35-45% increase in total protein content.

with the barstar gene are also available for these lines. Mustard lines with zero erusic acid and zero glucosinolate have been developed and are being tested in multilocation trials.

In cotton, pure lines have been developed for regeneration *in vitro* and used for developing insect resistant transgenics.

Molecular Biology and Medical Research

Advent of new biology has opened up unprecedented opportunities for biomedical research. These techniques have been utilized to identify, clone and sequence genes responsible for pathogenesis of a host of viruses, bacteria and parasites. On the basis of these studies antigens could be identified, monoclonal or polyclonal antibodies produced to purity for developing specific diagnostic tests and useful immunoprophylactic and immunotherapeutic vaccines. This has also helped in unravelling the molecular mechanisms responsible for cell multiplication, differentiation and death, thus providing valuable insights into the fields of developmental biology and oncology. An interesting outcome of these developments was not only to enhance the capabilities of medical researchers but the evolution of a whole generation of biomedical scientists in universities and research institutions.

Contemporary Centres of Biological Research Activity

Amongst the internationally known players in contemporary biology are -- the Indian Institute of Science, Bangalore; Tata Institute of Fundamental Research, Mumbai; the National Centre for Biological Sciences, Bangalore; Jawaharlal Nehru University, New Delhi; Madurai Kamaraj University, Madurai; Pune University, Pune; University of Hyderabad, Hyderabad; MS University, Vadodra; Banaras Hindu University, Varanasi; and the Bose Institute, Kolkata. Equally active are the centrally funded national laboratories such as the Centre for Cellular and Molecular Biology (CCMB) and Centre for DNA Fingerprinting and Diagnostics (CDFD), both in Hyderabad; Indian Institute of Chemical Biology, Kolkata; National Institute of Immunology, New Delhi; Centre for Biochemical Technology, Delhi; Central Drug Research Institute, Lucknow; Institute of Microbial Technology, Chandigarh; and the UNDP-aided International Centre for Genetic Engineering and Biotechnology, New Delhi (which has its twin at Trieste, Italy). Significant agro-biotech research goes on in the ICAR laboratories and state agricultural universities such as the ones at Hyderabad and Pant

Nagar.

Some of the more notable contemporary contributions in the area of modern biology and biotechnology in India are: (I) macromolecular conformation -- both theory and experiments, (ii) protein structure and function, (iii) designer peptides, (iv) glycobiology, (v) procaryotic transcription and drug action, (vi) enzymological approaches to drug design, (vii) vaccines and immunology, (viii) DNA typing and lineage analysis, (ix) transgenic plants, (x) expression vector systems for protein production, (xi) genomics, (xii) functional enzymology, and (xiii) molecular virology.

Several excellent hospitals and medical centres across the country are engaged in research and development activities in medical sciences. Some of these are the All India Institute of Medical Sciences, New Delhi; Sanjay Gandhi Postgraduate Institute of Medical Sciences, Lucknow; Christian Medical College, Vellore; Sree Chitra Tirunal Institute for Medical Sciences and Technology, Thiruvananthapuram; Postgraduate Institute of Medical Sciences, Chandigarh; the Cancer Research Institute, Mumbai, L.V.Prasad Eye Institute; Hyderabad; Sankara Nethralaya, Chennai; Jawaharlal Nehru Institute of Postgraduate Medical Research, Pondicherry; and Manipal Academy of Higher Education, Manipal. Mention must be made of their work in the areas of neurobiology, cataract, corneal and retinal research, cancer epidemiology and surveys, cardiomyopathy, leprosy, and medical genetics. (see chapter on Medical Sciences).

Biotech Products through Basic Research

With regard to marketing of products, a few notable examples have come through in the last few years which have involved active academic-industry collaboration. There are two companies, both of the medium range, that have been able to produce and market effective hepatitis B vaccine, through collaborations with academic institutions. Other products hitting the market through such combinations are streptokinase, interferon, and a general-purpose salt-inducible expression vector system, which is of great use for both academic and large-scale production of proteins from recombinant DNA technology. This vector has been patented in the US and licensed to a company there for global marketing. In addition there is a whole host of diagnostic kits that have been developed in academic institutions and given to industry for marketing and sales. Amongst the more notable of these is a diagnostic kit that exploits an agglutination method using whole blood to detect the presence of the AIDS virus. Laboratories are working on the development of a cholera vaccine, leprosy vaccine, and a vaccine against the Japanese encephalitis virus. While the leprosy vaccine has already been licensed to a firm, the other two are expected to do so shortly.

Turning to industry, perhaps the most prevalent biotechnology industry in India in almost every major city is that of tissue culture and micropropagation of horticulture and plantation crops. There are several major players such as SPIC, A.V. Thomas, Godrej, but there are also many small-scale micropropagators. It is interesting to note that during the severe winter of 1994-95 in Europe, tulips, the favourite of the Dutch people, were exported in cargo loads by air from Hyderabad to Amsterdam -- a biotechnological twist to the phrase 'carrying coal to Newcastle' (see chapter on Plant Sciences).

Among the major Indian drug firms utilizing modern biology are Ranbaxy, Dr. Reddy's Laboratories, Cadila, Unichem, Cipla and so on. The notable point about these firms is that each one of them is completely home grown and now has full fledged R&D laboratories associated with it. Apart from classical methods of drug discovery, several of them have dived right into the quest for new molecules. Three such new molecules have already appeared on the drug scene and are being licensed to firms outside the country. The firm Biocon, near Bangalore, is a success story in the custom-

production of enzymes and biochemicals for specific clients. Astra Zeneca has its research and development centre at Bangalore, where it concentrates on drugs for infective diseases, and screening of candidate molecules.

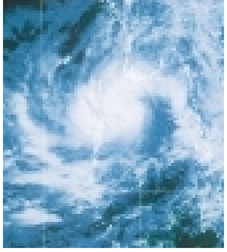
Today there are a couple of biotechnology suppliers, such as Bangalore Genii (started by a former academic), who supply to academic institutions their molecular biologicals, in competition with companies such as Sigma, Gibco - BRL, and Amhersham. These companies supply enzymes, oligos and probes, offer synthesis and sequencing services for both peptides and nucleic acids, and also offer minor laboratory equipment.

Research Funding and Support

The DBT not only funds extramural research projects but has also started institutions and centres of excellence in areas of modern biotechnology such as the National Institute of Immunology, National Centre for Cell Sciences, Centre for DNA Fingerprinting and Diagnostics, and the National Centre for Brain Research. It also suports university centres of excellence, somewhat in the fashion of the CNRS system in France. The DBT has come out with guidelines on recombinant DNA techniques, transgenics, and other issues (see chapter on Department of Biotechnology).

In addition to the DBT, other governmental agencies such as the Indian Council of Medical Research (ICMR), Indian Council of Agricultural Research (ICAR), Department of Science and Technology (DST), Council of Scientific and Industrial Research (CSIR), and the Bureau of Research in Nuclear Sciences (BRNS), as well as the Universitiy Grants Commission are other sources of research funding in biotechnology in the country. It has been estimated that close to 60% of all grants-in-aid offered by these national agencies goes into areas of modern biology. The governmental funding for science and technology amounts to about 1 per cent of its budget.

Professional associations in the area of modern biology have also been active for over two decades now. Notable amongst these are the Society of Biological Chemists of India (which is the oldest, over 50 years in existence), Indian Society of Cell Biology, Indian Immunological Society, Association of Indian Microbiologists, Indian Biophysics Society, and the informal and yet very effective annual meeting called the Guha Research Conference. These have led to camaraderie and cooperation between investigators within the country so that and scholars, exchange of materials and sharing of equipment has become far more common in the areas of biotechnology and modern biology than in other branches of science in India.



CHAPTER XV

PLANT SCIENCES

Botany is a mother science which has given birth to several branches, each being pursued as a speciality. The study of botany has undergone a tremendous change in the past 50 years and is presently called Plant Sciences to cover its wide scope. Early contributions to botanical knowledge were mainly made in colleges and universities by eminent individuals, who were fired by a spirit of nationalism. By talent and devotion they built schools of botanical learning. Undoubtedly, India has worldwide recognition in embryology, palaeobotany, taxonomy, cytology, cytogenetics, plant breeding, plant tissue culture and morphogenesis, and ecology. I.H. Burkill (1965) has compiled *Chapters on History of Botany in India*. B.M. Johri (1994) has edited two volumes on *Botany in India: History and Progress*, sponsored by the INSA. What proceeds is a summary of achievements in certain spheres of the subject.

REPRODUCTIVE BIOLOGY

A discipline in which India holds leadership in the botanical world is embryology, nurtured by P. Maheshwari at Agra, Dacca and Delhi. *An Introduction to the Embryology of Angiosperms* authored by him in 1950 was, for many years, an authoritative textbook used the world over. Several important works such as *Embryology of Angiosperms* and *Comparative Embryology of Angiosperms*, by other authors have appeared since then. Besides investigating the embryology of seed plants of diverse families, and using the data generated for comparative and evolutionary purposes, outstanding contributions have been made in experimental embryology such as test-tube fertilization, pollen-pistil interaction, sexual-incompatibility, wide hybridization, nucellus and endosperm culture. In pollen biology the Indian endeavour covers morphology, aerobiology in relation to allergies, pollen viability, storage, germination and more recently biotechnology.

In plants that bear fruits with numerous seeds, there is intense competition among seeds for resources. It is only recently that studies have been initiated towards the understanding of concepts such as clutch-size, sibling-rivalry, parent-offspring conflict and neighbourhood effect by researchers at the University of Agricultural Sciences (UAS), Bangalore. These authors have provided recent evidence that only one out of 30 potential seeds develop in the *Jamun* tree (*Syzygium cumini*). The dominant seed draws the nutrients at the expense of the others. It also produces a chemical inhibitor (an indole compound) that suppresses the subordinate seeds.

It is regrettable that reproductive biology, especially breeding systems and gene flow in the identification of reproductive constraints, has not been studied in India in many economically important plants, including forest trees (except at a few centres such as Chandigarh, Jammu, Lucknow, Waltair and Delhi). For any tree-breeding programme, basic information on reproductive biology is essential. For instance a study made at Delhi on reproduction by seed in the ancient Indian medicinal plant guggul (*Commiphora wightii*) showed that the plant is a non-

pseudogamous apomict (not involving male participation) with nucellar polyembryony followed by autonomous endosperm development. Apomixis -- the formation of seeds without fertilization -- occurs in many grasses, dandelions and parthenium. Apomixis is now being studied at the molecular level with the hope that any gene(s) that regulate it might be introduced to fix hybrid vigour, to save time, labour and money. Genes which confer apomixis act at the stage of female meiosis. Therefore, it is essential to ultimately engineer apomixis in crop plants. Scientists at the CCMB have discovered a novel gene called *DYAD* in *Arabidopsis* which is involved in the control of female meiosis in plants.

Palaeobotany

Pioneering research work has been done at the Birbal Sahni Institute of Palaeobotany, Lucknow.

Four postage stamps released on the occasion of the Golden Jubilee of the Birbal Sahni Institute of Palaeobotany, depicting fossils and reconstructions.



Photo: BSIP, Lucknow

The creation of a new order Pentoxylales, a group of Jurassic fossil gymnosperms from Rajmahal hills in Bihar; verification of Wagner's theory of continental drift, providing scientific evidence for the Himalayan uplift, studies on stratigraphy relating to the classification of the Gondwanas; and origin, composition and reconstruction of the *Glossopteris* flora are some of the contributions which have received international recognition. Pollen with angiospermoid characters have been described from intertrappean sediments of Rajmahal basin (118 Ma). Besides reporting fossils of wild seeded banana and coconut, the Indian palaeobotanists have proved that the present Kutch region had luxuriant moist evergreen to deciduous vegetation. The earliest record of a mango fossil leaf from north-east India dates back to 55 Ma. Analysis of microfossils has enabled palaeobotanists to answer questions that have a bearing on coal, oil and natural gas. Other contributions of Indian palaeobotanists relate to changing palaeoclimates, migratory pathways of plants and causes of mass extinction. Coccoid and rod-shaped bacteria have been discovered in the sediments of Kudremukh iron formation, dating back to 2.6 billion years. The early photosynthetic, oxygen producing cyanobacteria isolated from stromatolites are also dated 2.6 billion years.

Biodiversity and Systematics

India is one of the 12 Megadiversity countries and has all the 13 biomes found in the world, with two major hotspots out of a total of 18. Importantly, India is one of the global centres for domesticated biodiversity (accounting for 160 domesticated species including rice, beans, sugarcane, citrus, mango, banana, eggplant, black pepper and cucumber). The approximate total number of plant species (including fungi and bacteria) recorded until now is between 45,000 and 49,000. These are distributed in the following groups: Angiosperms (flowering plants) 15,000-17,000; Gymnosperms 64; Pteridophytes 1,022; Bryophytes 3,700;Lichens 2,400; Fungi 23,000; Algae 2,500 and Bacteria 1,000. The exact numbers are not yet finally established. Among these there are 5,100



Variation in fruit shape, size and colour of egg plant or brinjal (Solanum melongena). Egg plant originated in India and was introduced to the other parts of the world.

endemics in angiosperms (1,600 in Western Ghats and 3,500 in Eastern Himalaya). These figures highlight the richness of our flora and the incompleteness of our knowledge of plants. About 2,000 species are threatened. Out of 120 endangered species, 60 are prioritized for conservation.

Non-Vascular Cryptogams: Indian botanists have carved a name for themselves in world botany for their studies on algae from soils, fresh water and marine environments. Whereas the school of Algae at Madras University led by M.O.P. Iyengar made extensive collections of marine brown and red algae, some of his students took up studies on the bluegreen algae or Cyanophyceae (now termed Cyanobacteria) and diatoms and wrote authoritative monographs. At the Banaras Hindu University (BHU) Y. Bharadwaja and R.N. Singh and their students specialized in the taxonomy, ecology and cytology of algae, physiology (notably nitrogen fixation), genetics and cytology. The first reports of the occurrence of viruses in the bluegreens and genetic recombination were from BHU using antibiotic-resistant mutants of *Anacystis nidulans*. The presence of plasmids and the role of UV radiation on growth, survival, adaptation and mutagenesis were also established for the first time at BHU. Other centres of algal research are at Allahabad, Lucknow, Jammu and Mysore. Applied aspects (such as extraction of biologically important compounds) from marine algae and use of bluegreen algae for scavenging toxic substances and heavy metals are being pursued at several centres.

More than 2,000 fungal genera accounting for 1/5 of the total global representation of fungi are reported from India. An enormous amount of work has been done on the taxonomy, morphology, reproduction, physiology, pathology (T.S. Sadasivan), genetics and industrial aspects of fungi (M.J. Thirumalachar). One hundred and eighty- five new genera of fungi have been described. The largest number belong to Deuteromycotina. Authoritative works have been published on Hyphomycetes, Myxomycetes and Clavariaceae (K. S. Thind). The physiology of parasitism and mechanism of resistance to fungal diseases have been pursued at the universitites of Madras, Calcutta and Allahabad (R.N. Tandon). The role of mycorrhizae (both ectotrophic and VAM) in the improvement of plant nutrition (especially phosphorus uptake), drought tolerance, suppression of soil-borne pathogens and reclamation of derelict lands are important current activities at UAS, Bangalore; Osmania University, Hyderabad; and University of Delhi (DU). The study of lichens was neglected until 1947. The pioneering efforts done at Lucknow, Pune and Kolkata have shown that over 2,000 species occur in India.

Bryophytes, the first plants to migrate from water to land are evolutionarily and ecologically significant. India accounts for nearly 18% of the world's bryophytes. The Lahore School of Bryophytes established by S.R. Kashyap was continued by his students, P. N. Mehra and R.S. Chopra at Chandigarh and by S.K. Pande at Lucknow. The evolutionary theories put forth by Mehra on the origin of thalloid forms from the

foliose habit and evolution of the marchantiaceous thallus have been highly valued in academic circles. Cytotaxonomic work on mosses (Chandigarh) and taxonomy and palynology of the bryophytes by Ram Udar at Lucknow have resulted in landmark publications.

At the Calcutta University, Gangulee took up the assiduous task of compiling the monumental work, *The Mosses of Eastern India and Adjacent Regions* (1969-80) in eight fasciles. The best known fossil liverworts (notably *Hepaticites nidpurensis*) were described from the Triassic beds of India by D.D. Pant.

Bryophytes have been used for ecological, geobotanical and geochemical studies in Kumaon Himalaya. They are also excellent materials for experimental studies on morphogenesis, physiology and molecular biology. Notable among the Indian contributions are studies on (i) control of spore germination, (ii) auxin regulation of protonemal differentiation from chloronema to caulonema and its regulation by cyclic AMP (at TIFR) Bombay, (iii) bud induction and formation of gemmae. Several other investigations include control of apogamy, apospory and sexuality by light, tempertaure and plant growth regulators (PGRs) and sugars included in the medium, and (iv) production of antibiotics.

Pteridophytes and Gymnosperms: Ferns and fern allies (Pteridophytes) ruled the dynasty of plant world during the carboniferous age (325 million years ago) as giant lycopods. They have now been relegated to a secondary position in botanical hierarchy. Over 82 species of Indian pteridophytes are vulnerable or extinct. Besides their important role in phytosociology, they are prized for their high ornamental value. The fascinating aspect that has attracted evolutionists to pteridophytes, both living and fossil, is incipient heterospory, leading to seed habit.

Azolla, the tiny aquatic fern harbours *Anabaena azollae*, a nitrogen fixing cyanobacterium in its pouches. Its role as a biofertilizer in tropical paddy fields has been studied at Varanasi and Cuttack. Plant scientists at Chandigarh and Patiala have carried out extensive work on the cytotaxonomy and ecology of pteridophytes. They have also started the *Indian Fern Journal*. Other active groups engaged in research which have added substantially to our knowledge of taxonomy, palynotaxonomy and reproductive biology of this group are from the National Botanical Research Institute (NBRI), Lucknow, and from universities of Lucknow, Allahabad, Panjab, Punjabi (at Patiala) and Calicut. Pteridophytes have also served as model systems for understanding morphogenesis. Several live collections of ferns and their allies have been conserved in botanical gardens in the above mentioned institutions. Owing to habitat destruction and over-collection by botanists and horticulturists, pteridophytes such as *Psilotum* and tree ferns have become rare and endangered at several original sites.

Gymnosperms are seed-bearing plants that lack fruits. They constitute a major component of the Himalayan forests as conifers. Cycads and gnetopsids are important groups in the study of plant evolution. B. Sahni's creation of a new group of fossil plants – the Pentoxylales – is a fundamental contribution to the field of gymnosperms. Befittingly *Pentoxylon sahnii* features in the emblem of the Birbal Sahni Institute of Palaeobotany (BSIP) and of the journal *The Palaeobotanist*.

Scientists of BSIP, D.D. Pant and his students at Allahabad, and U. Sen and his collaborators at Kolkata have enriched our knowledge of *Glossopteris* flora, Mesozoic gymnosperms and palynology. Structural, embryological, cytological aspects, and cytogenetical evolution, genetic architecture and taxonomic accounts of extant gymnosperms have been studied by researchers at Delhi, Lucknow, Chandigarh (P.N. Mehra), Allahabad, Chennai (B.G.L. Swamy) and Bangalore. Monographs and books have been prepared on *Abies*, *Cedrus*, *Picea*, *Pinus*, *Gnetum*, and *Ephedra*. Studies on population structure and reproductive

biology, with special reference to breeding system in pines have been carried out by P. D. Dogra. The cycads, often called living fossils, are disappearing from their natural habitats in India and need special efforts for conservation.

Angiosperms: The Botanical Survey of India (BSI) with its headquarters in Kolkata and nine circles was, has been, and will be the nucleus for preparing an inventory of plant resources of the country. This is a stupendous task and will have to be shared by teachers and scholars in colleges and universities and professionals in other institutions. The major achievements of BSI in the post-Independence era are the launching of a 35-volume *Flora of India* project, of which six have been published. Numerous local, district and state floras have appeared. The BSI has a chain of 11 herbaria, of which the Central National Herbarium, Howrah, is the largest. The total holdings in the BSI herbaria exceed 2.48 million, including 11,892 precious type specimens of the Indian Flora. Computerization of the herbarium sheets has been started by BSI. On the basis of floristic/taxonomic studies since 1964, over 1,500 taxa new to India and about 700 plants new to science, including over 26 genera have been added. After careful evaluation of the status and threat perceptions, Red Data Sheets on 1,182 species have been compiled. Data on 708 are available in print.

It is paradoxical that when there is serious global concern for the conservation of biodiversity, India should face an acute shortage of experts who can study, evaluate and explain the role of the wide variety of organisms in nature. The teaching of taxonomy is being neglected and taxonomists are undervalued not only in society but even in scientific circles. However, a few dedicated taxonomists have been relentlessly taking up floristic surveys and taxonomic studies. They have brought to light not only new species but have also uncovered several plants reported to be either extinct or extremely rare. Some of their contributions are: *Flora of Ladakh*, *Alpine Flora of Kashmir Himalaya*, *Flora of Indian Desert*, *Flora of Meghalaya*, *Flora of Tamil Nadu Carnatic and Excursion Flora (Tamil Nadu)*, *The Flora of Karnataka* (two volumes), *Flora of Silent Valley*, *Flora of Udupi District*, *Flora of District Garhwal* and *Flora of Shimoga District*. The family Hydatellaceae (so far thought to be endemic to Australia) has been reported to occur in Maharashtra.


Photo: Pramod Tandon

***Paphiopedilum villosum*, the Lady's slipper orchid from Meghalaya.**

As a signatory to the Convention on Biological Diversity (CBD) held in Rio de Janerio in 1992, it was obligatory for India to commit itself to capacity building in taxonomy and take up exploration and preparation of an inventory of living organisms. Following the recommendations of a Workshop held in Jaipur for this purpose, the Ministry of Environment and Forests (MoEF) has set up an All India Co-ordinated Project on Taxonomy. The Project has organized specialist groups drawn from Universities, Botanical and Zoological Surveys of India to take up taxonomic work on animal viruses, bacteria and archaea, algae, fungi, lichens,



Photo: David Kothamasi

Many islands in the Andaman and Nicobar group are yet to be floristically explored.

bryophytes, pteriodophytes, gymnosperms, palms, grasses, bamboos, orchids, helminthes and nematodes, Microlepidoptera and Mollusca. Training in plant and animal biosystematics has also been recognized as an important component.

The taxonomic issues that need to be addressed in this century are mostly those that require interfacing of systematics and other disciplines. These include bioprospecting, conservation biology, ecosystem management and bioremediation. The other priority issues to be probed are inventorying and monitoring of plant diversity, particularly in areas which are unexplored, assessment of conservation status of species and roles of species in communities and ecosystems.

Cytology

Early efforts were addressed to the enumeration of chromosome number, size and karyotype of plants belonging to various groups at Chandigarh, Kolkata, Waltair, NBRI, BHU, Dharwar etc. Cytological information has been used as a criterion for evolution and genotoxicology. The book *Chromosome Techniques: Theory and Practice* is used the world over. Another most useful compilation is *Chromosome Atlas of Flowering Plants of the Indian Subcontinent* (1986), covering 6,973 species, 2,221 genera and 286 families. Banding techniques, chromosome painting, quantification of DNA, *in situ* nucleic acid hybridization and molecular aspects of genome organization are being pursued in India.

Plant Tissue Culture

Plant tissue culture, an off-shoot of human curiosity has presently become an essential component of plant biotechnology. Through the efforts of pioneers in France, USA, U.K. and Germany, plant tissue culture

Trichopus zeylanicus (locally called arogya-pacha) is a wild plant that occurs in the Agasthyamalai hills of Kerala. It yields a drug that acts as an anti-fatigue and restorative agent. Scientists of Regional Research Laboratory (RRL), Jammu, and later of Tropical Botanical Garden and Research Institute (TBGRI), Kerala have carried our ethno-pharmacological studies on this plant and have prepared a formulation called Jeewani. The technology has been transferred to Arya Vaidya Pharmacy, Coimbatore. Fifty per cent of the monetary benefit from this transaction is being shared with the Kani tribe. This is the first example in which ethnobiological studies have resulted in tangible benefits to a tribal community. There are a large number of wild plants with potential use in agriculture, horticulture and medicine, requiring attention.

spread to various parts of the world. It was P. Maheshwari who started the first tissue culture Laboratory in India at DU in the 1950s as he foresaw the value of this technique in experimental embryology. Teachers trained abroad returned to Delhi, Baroda and Pune from where the interest spread to other universi-tites and CSIR laboratories such as NCL, NBRI, RRL(Jammu), and to BARC, Mumbai. The main benefits derived from tissue culture are: control of organogenesis, elimination of breeding barriers, micropropagation, disease detection and eradication, somatic embryogenesis, use of protoplasts, somatic hybridization, somaclonal variation, detection of genetic variability *in vitro* and production of transgenics. The discovery of androgenic haploidy at DU opened up an entirely new field of research in the production of pure lines of crop plants resulting in reduction of time and labour for exploiting hybrid vigour, especially for rice in China and later for other cereals. Very recently gynogenic haploids have been produced in mulberry.

Undeniably the most useful outcome of tissue culture has been in the micropropagation of ornamentals, agricultural and plantation crops, fruit and forest trees. Laboratory research on micropropagation of plants of economic importance (*Citrus, Eucalyptus*, bamboos, teak, poplar, banana, sugarcane, turmeric and cardamom) has been scaled up to near commercial level. The Asian bamboos have long flowering cycles and come to mast seeding once in 12-120 years. The first demonstration of micropropagation in bamboo using seed callus cultures was done in Delhi and over 10,000 plants were transferred to the field successfully. Several groups working in India and abroad have now demonstrated that micropropagation in bamboos can be accomplished, starting from vegetative parts. The pioneering work done at Delhi and NCL, Pune, led to the discovery that bamboo plantlets can come to flower *in vitro* precociously.

Tissue culture has been effectively used for multiplying and storing economically important, endangered (e.g. *Nepenthes khasiana*), threatened (Himalayan orchids) and biologically incompletely understood plants (Podostemaceae) and medicinal plants (*Dioscorea, Coptis teeta, Valeriana wallichi, Podophyllum hexandrum, Picrorhiza kurroa*) at North-Eastern Hill University (NEHU), DU, NBRI, NCL, BARC, CIMAP and Institute of Himalayan Bioresources and Technology (IHBT), Palampur.

The DBT has established six centres in India to provide hardening facilities for laboratory-raised plants and Micropropagation Technology Parks at TERI and NCL. The National Facility for Plant Tissue Culture Repository (also started by DBT) located at the NBPGR, has now been taken over by the ICAR. Collection, evaluation, introduction, exchange and conservation of germplasm, storage of elite plants, rare hybrids, and germplasm of vegetatively propagated plants and of plants bearing recalcitrant seeds in the form of tissues or embryonal axes in cryobanks are being practised at NBPGR.

Ecology and Environmental Studies

Plant ecological research in India can be traced to renowned ecologists— R. Misra of Banaras Hindu University (BHU), Varanasi, and F.R. Bharucha of the Institute of Science, Mumbai. Many of the other ecology centres in India owe their origin to persons directly or indirectly trained by Misra. The French Institute (Institüt Francais) at Pondicherry initiated studies on vegetation cartography in the 1950s.

In the beginning years attention was paid to the ecology of individual species in the ecosystem. Presently advances



Photo: Pramod Tandon

The only pitcher plant in India Nepenthes khasiana occurs in the north-eastern regions of India. Scientists of NEHU have propagated this plant in tissue culture and have introduced the plantlets to the natural habitat.


Photo: NBPGR, New Delhi

A corridor for modules in the National Seed Bank of NBPGR for storage of seeds at -20°C.
Inset: Cryotanks for storing seeds and embryonal axes in liquid nitrogen.

have been made in the study of aquatic and wetland ecosystems, marine and mangrove ecosystems. In the study of forest ecosystems focus was shifted to nitrogen budget, mineral recycling, above ground and below ground (fine root) biomass production, functional analysis of effects of changes in land use, phenology of trees and vegetation analysis.

The BHU School has done commendable work on population differentiation, weed ecology, habitat conservation, productivity, energy flow, nutrient cycling and ecology of global change. The ecologists of this school have quantified biomass production and nutrient cycling of pine and oak forests in the Central Himalaya. They have shown that high C:N ratio of litter in pine leads to immobilization of available soil nitrogen, making the habitat inimical to species such as oaks that demand high amounts of nitrogen. This group has carried out detailed analysis of human and forest interactions in the Central Himalaya. The agro-systems in this part of the Himalaya are centres of massive energy consumption and their viability depends on the supply of energy from forests. A significant finding is that these forests are a source of CO_2 rather than a sink. The work on Ganga water was crucial in creating public awareness and inducing public and government participation in the form of Ganga Action Plan. The international journal *Tropical Ecology* was started at BHU and has maintained a high profile, acting as a vehicle to disseminate knowledge generated in and about the tropics.

The ecologists of the French Institute, Pondicherry, in collaboration with the ICAR and State Forest Departments prepared the first vegetation map of Peninsular India in 1956. With the availability of satellite imageries, another project was launched in 1973 for the cartography of the forests of the Western Ghats at a scale of 1:25,0000. These maps include details of flora and endemic species in addition to forests, grasslands, and wastelands. Analysis of the maps indicates the percentages of forest cover according to vegetation types. These data coupled with ecological studies in sensitive forest areas have been invaluable in strengthening conservation efforts. Other ecologic aspects studied at the Institute deal with bioclimatology and climate change with reference to deforestation.

Sustained plant ecological work at Rajkot and later at Agra has led to two significant discoveries: (i) 25 ecotypes of the desert grass *Cenchrus ciliaris* and nine of *C. setigerus* have been brought to successful cultivation in India and America, (ii) highest production, perhaps in the country, is in semi-arid areas like Agra Region with fresh or old alluvia, disproving the concept that semi-arid areas are next to arid and vulnerable to desertification (because native vegetation is dominated by C_4 plants with the highest water use efficiency).

Several investigators have studied the individual

effects of SO_2, fluoride and ozone and particulate matter on plants under controlled conditions at BHU, NBRI and JNU. The combined effects of pollutants with respect to injury symptoms have also been studied. The mechanism that prevents toxic effects of heavy metals on the metabolism of cyanobacteria and plants are being studied (BHU). The study of allelo-chemicals released by the weedy species to suppress other plants in the ecosystem has also received recent attention. Bioclimatic studies have been carried out to correlate vegetation distribution in the origin of tropical evergreen forests. That increasing emissions of greenhouse gases, such as CO_2, methane, CFCs, and nitrous oxide, are responsible for global warning is well-established. Among the sources of methane emission India, China and other Asian countries were considered as major contributors with huge areas of rice cultivation. Research carried out by IARI plant physiologists and ecologists at BHU has clearly indicated that methane emanating from the rice fields is not a major cause of global climate change as claimed by some western scientists.

Much of the ecological research had been carried out as if people did not matter. For the first time in India, a leading plant ecologist and his students began doing ground level research at the NEHU, and subsequently at JNU, in the interphase area of linking ecological and social processes. This group made an interdisciplinary case study of shifting cultivation (jhum cultivation) in north-east India, centred around sustainable management of natural resources. The information generated has been synthesized and published in 350 papers and a dozen books. Many traditional societies have accumulated a whole lot of empirical knowledge centred around the economic value of plant and animal species. The main contribution of this group has been to unravel the connection between Traditional Empirical Knowledge (TEK) and natural resource management and landscape management. This work has received international attention. Several strategies have been suggested by them for the improvement of landuse and resource management amongst mountain societies. The Nagaland Experiment of 1976-82 in rural management through Village Development Boards (VDBs) implemented by the government with support from India-Canada Environment Facility, has drawn largely from the research results of the NEHU ecologists..



A jhumed (slash and burn) area in Meghalaya.

The political economy of forest resource use has been studied by scientists at the Centre for Ecological Sciences, IISc. This group has brought to light the devastating long-term consequences for short-term gains by state governments. Bamboos were sold to paper mills at a throw-away price of just one rupee per tonne, whereas the basket-weavers had to levy in paying more than Rs. 5,000 per tonne in the Uttra Kannada district of Karnataka. Scientists at this Centre have also studied the ecological History of India and are compiling People's Biodiversity Register through participation of schools and colleges.

The restoration of degraded lands has been studied at BHU and Delhi. An important success story of DU scientists is the rehabilitation of a three-storeyed vegetation in the limestone-mined areas at Bhatta in Mussorie hills and morrum mined-out area of Bhatti wildlife sanctuary in Delhi and

extremely desertified land of Asola wildlife sanctuary, using a consortium of microbes belonging to different functional groups, associated with wild legumes and grasses.

PHYSIOLOGY

The rudiments of plant physiology can be traced to pioneers like J.C.Bose at Kolkata and Dastur in Mumbai. Parija (Cuttack), Sri Ranjan (Allahabad), R.S. Imamdar (BHU), T.Ekambaram (Chennai) and J.C.Sen Gupta (Kolkata) built active schools. The mechanism of regulation of stomatal movements and the various morphological, physiological and biochemical strategies to withstand drought, salinity, alkalinity and cold stress are being investigated (Tirupati, Hyderabad, IARI). Availability of water is a crucial factor that limits crop growth and productivity. With predictions about acute shortage of water in the near future and changing rainfall pattern, plant physiologists are giving serious attention to crop-water relations. Water Use Efficiency (WUE) is the ratio of the amount of biomass produced over a period of growth to the total amount of water transpired. Scientists at UAS, Bangalore have developed a method of estimating WUE by weighing a large number of plants in containers (mini lysimeters) on a daily basis. There is genotypic variability in WUE. Plants descriminate against heavy isotope of carbon (^{13}C) during photosynthesis. Since intercellular CO_2 concentration determines both carbon isotope descrimination and WUE, a strong inverse correlation exists between these paramters. In genotypes with high WUE, despite high transpiration, mesophyll efficiency for carbon reduction is also high. For rapid screening of genotypes with superior mesophyll efficiency, the Bangalore scientists are using the Isotope Ratio Mass Spectrometer (IRMO, a National facility set up by DST and DBT), which can monitor $^{13}C/^{12}C$, $^{18}O/^{16}O$, $^{15}N/^{14}N$ ratios on a continuous flow basis. This set up further facilitates analysis of these traits using molecular markers.

Basic and applied aspects of photosynthesis have been studied by several groups with emphasis on photochemistry, biochemistry and biomass production (JNU, NBRI, MKU, University of Hyderabad). In the mid 1960s the C_4 pathway was discovered in tropical plants which had high productivity. Plant physiologists at IARI noted that in *Sorghum* and *Pennisetum* a change from C_4 to C_3 pathway occurred after flowering. This was the first explanation that C_3 pathway is basic whereas C_4 can change with environment and phenology. Research done at Tirupati showed that certain plants are intermediate between C_3 and C_4 in leaf anatomy and biochemistry and also that the same plant may bear leaves with C_3 and C_4 photosynthetic pathway. IARI workers explained that heterosis in yield increment is the culmination of complementary relation between the 'source' (foliage) and 'sink' (grains). The heterosis in height and leaf area are the result of multiplicative effect of their component characters which show dominance/partial dominance.

Yet another area that has been in the forefront is the understanding of root-shoot signalling as a drought resistance strategy. Signals have been characterized involving the stress hormone abscisic acid (ABA) as a predominant positive signal and ions (calcium, nitrite) and cytokinins as negative signals. Electrical signals are indeed rapid and they can cause closure of stomata in the leaves instantaneously preventing transpiration (UAS, Bangalore).

A school of mineral nutrition was established at the Lucknow University by S. C. Agarwala to investigate the adequate dosage of micronutrients for important Indian crops and to establish critical limits of deficiency and toxicity. Of special significance is the metabolic and developmental role of micronutrients, especially zinc.

Several groups in India have studied nitrogen metabolism and the regulation of nitrate and nitrite reductase enzymes. Nitrogen fixation by free-living bluegreen algae and other bacteria, and symbiotic prokaryotes has been studied extensively. Pioneers in the area of biological nitrogen fixation are R. N. Singh and G.S. Venkataraman and their students and

scientists at Kalyani. The attention of scientists at JNU has been focussed on the regulatory aspects of nitrate reductase (NR) in response to light (NR is synthesized in response to phytochrome), hormones, nitrate, ammonium, amino acids and so on. These workers have also shown the phytochrome regulation of Ca^{+} fluxes and its effects on the turnover of phosphoinositide cycle.

S. M. Sircar and his students at Kolkata were pioneers in India in the physiology of flowering. In later period his group isolated gibberellins from mangroves and water hyacinth. Cytokinins were extracted by other workers from several plants. According to plant hormone researchers of IISc, Bangalore, cytokinins and auxin are involved in the production of haustoria in the parasitic plant *Cuscuta* even without organic contact with the host. An entirely new group of antigibberellins-- the cucurbitacins -- which are widespread in the family Cucurbitaceae were reported from Kolkata. Indian scientists have also provided extensive evidence for the growth regulating properties of polyamines. An impressive amount of work has been done on the physiologial effects and agricultural applications of plant growth regulators (PGRs) and their antagonists, especially on the rooting of cuttings, induction of flowering, parthenocarpy, biennial bearing in mango, sex expression, induction of male sterility, defoliation, fruit ripening, and retardation of senescence in flowers. Special mention is made of the work of K.K. Nanda on the induction of flowering in the short day plant (SDP) *Impatiens balsamina* by gibberellins under non-inductive conditions and in duckweeds by phenolics, especially salicyclic acid and also by chelating agents at DU.

A brief account of Plant Molecular Biology is covered in Chapter XIV.

Ethnobotany

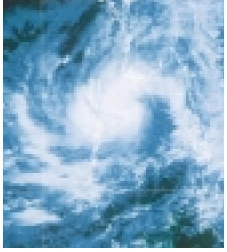
An aspect of botany which has received recent attention and recognition as an organized discipline in India is ethnobotany, defined as the total direct relationship between humans and plant kingdom. Detailed surveys have been carried out to record the knowledge systems used by tribals and other ethnic communities in the use of plants and other products. Publications such as *Contributions to Indian Ethnobotany*, *Dictionary of Indian Folk Medicine*, *Ethnobotany and Notable Plants in Ethnomedicine* of India provide enormously rich information.

Botanical Journals and Wealth of India

A few prestigious periodicals that publish the major papers from Indian scientists are: *Journal of the Indian Botanical Society*, *Phytomorphology*, *Palaeobotanist*, *Nucleus*, *Tropical Ecology*, *Indian Phytopathology*, *Indian Journal of Genetics and Plant Breeding* and *Rheedea*. The *Wealth of India* is a unique encyclopaedic publication consolidating all available information in Indian economic raw materials (plants, animals and minerals) and industrial products. This work is published by the National Institute of Science Communication (NISCOM, formerly PID), CSIR, and has gained respect in the world of learning. The number of entries on plants alone exceed 5,000 species.

Conclusion

The above account, by no means exhaustive, brings to the fore certain aspects of plant science research in India. From individual efforts with meagre facilities, botanists have proceeded to group activities involving persons from other disciplines. As a humanistic science, botany has begun to embark on areas with deep social concerns. There is still a vast scope for generating new knowledge through basic science to maximize crop yields per unit area, minimize stresses, secure assured water supply, conserve plant germplasm, cultivate plants that yield products of high economic returns and ensure sustained availability of non-timber forest products to raise the incomes of tribals and the rural poor. What the country needs is a proper blend of inputs from Botany, Microbiology, Agriculture, Chemistry, Forestry, Economics, Sociology and Management.



CHAPTER XVI

Animal Sciences

Introduction

India is endowed with a rich and diverse fauna due to its unique biogeographic location, varied climatic conditions and enormous eco- and geo-diversity. India is one of the few countries that has the unique distinction of having a wide spectrum of biogeographical areas --montane, coastal, tropical rain forest and desert. The fascinating range of organisms that these regions harbour and their complex ecological relationships give India its unique and productive status. The species, ecological and genetic diversities of this vast land are all needed to preserve India's ecological systems. Towards this end, a number of premier national institutes and universities are undertaking path-breaking and painstaking research and documentation, which will ultimately be instrumental in halting the present rate of degradation of our environment and lead to restoration of the environment for equitable and sustainable development.

India's Faunal Wealth

A total of 89,500 species of animals, from Protozoa to Mammalia, have been described inhabiting the Indian subcontinent. This constitutes 7.28 per cent of the total world animal fauna. However, according to experts what has been recorded may be only a small fraction of all those that actually exist. Some estimates put the number of species in India to be around 5,00,000. The majority of the unexplored ones will come from groups such as the Protozoa, Nematoda and Insecta. India is one of the 12 megabiodiversity centres of the world with two very significant hotspots of animal diversity, one in the North-Eastern Region and the other in the Western Ghats. Earlier work on the Indian fauna was catalogued in several volumes under the title *Fauna of British India*. Its name was changed to *The Fauna of India* series after Independence. In the pre-Independence days Europeans showed a great fascination for the study of Indian fauna.

Beginnings of Zoological Studies

The establishment of the Zoological Survey of India (ZSI) in 1916 helped to identify and characterize the rich fauna of the Indian subcontinent. Since its inception, scientists of the ZSI have been carrying out regular surveys for the purpose of collection of animal specimens for taxonomical study. The contributions of S. L. Hora during 1930s on the study of fishes and that of Salim Ali during the last few decades of the past century on birds are of immense significance. Research in zoology remained largely confined to areas such as morphology, taxonomy and life cycle studies, well into the middle of the 20th century.

The teaching of zoology at degree and postgraduate levels was initiated in the Universities of Madras, Calcutta and Bombay started in 1857. This structured teaching was further expanded specially after Independence in a number of other universities. Teaching led to initiation of research almost simultaneously in many of these educational institutions. The Government of India provided sufficient funds directly to the Universities of Delhi and Banaras and Aligarh Muslim University from 1947 onwards which helped to focus on teaching and



Highly endangered species of Asiatic lion at Gir forest in Gujarat.

research in zoology. Several other universities and goal-oriented institutes were later established by both the Central and State Governments to impart teaching and research in various science subjects including zoology and marine biology. From those early days, and in keeping with the modern trend, research and teaching has diversified into various allied areas such as physiology, biochemistry, cell and molecular biology, immunology, genetics and development. During the past three decades significant progress has been made in several universities and research institutions in India. Research in the field of zoology and marine biology has been initiated from gross structure of the organism to its constituent cells leading to the understanding of intracellular functions at the molecular level. The focus at present is towards application of knowledge garnered over the years for betterment of the quality of our lives and environment.

The establishment of the Indian Agricultural Research Institute (IARI) at New Delhi, Forest Research Institute (FRI) at Dehra Dun, National Institute of Oceanography (NIO) Goa and the Central Arid Zone Research Institute (CAZRI) at Jodhpur, helped in initiating specific research on economically important fauna of India. The research work carried out by scientists at these institutes contributed significantly to the study of economically important insects, nematodes, protozoans, helminths and other parasites. In addition, the interaction of humans with various animals was deciphered in these studies. The study of many of the parasites, parasitoides, and pests, is now regarded as a part of agricultural or medical sciences, in particular entomology, nematology, medical and veterinary parasitology, rather than zoology.

Developmental Biology

One of the challenges in zoology is the study of the events that lead to the adult organism starting from a fertilized egg. Developmental biology has been a subject of specialization in several institutions. There are two major path-breaking findings made by Indians working in India. They relate to the area of pattern formation as is seen in limb development. Both findings have received wide acknowledgement and international acclaim . An eminent scientist and his student working at the University of Rajasthan have shown (1978) that vitamin A and its derivatives could not only cause malformations in amphibian limbs during normal development, but, if applied after the larval limb was amputated, could lead to the regeneration of both the missing (amputated) body part as well as of extra, supernumerary, limb parts. Strikingly, at times the extra part was a mirror-imaged duplicate of the normal regenerate. The finding led to an explosion of research into the role of retinoids in early development that continues to this day. In particular, investigations have been focused on the possible role of retinoids as 'morphogens' and evocators of specific patterns of gene expression.

In 1992, a team of zoologists at Utkal University, Bhubaneswar, showed a remarkable effect of vitamin A treatment applied to tadpole larvae whose tails had been amputated. They discovered that on occasion the amputated tail would regenerate and give rise to a limb (leg), in effect converting what had been a tail into a leg. This was the first demonstration of a homeotic transformation in a vertebrate. Once again, a piece of pioneering research carried out in India initiated a line of work followed by many others worldwide.



***Uropeltis rubromaculatus*, a reptilian species from Western Ghats.**

Extensive studies were conducted in the field of developmental genetics using the fruitfly, *Drosophila melanogaster* at TIFR. Ultrastructural studies on the cell organelles were conducted using various types of specimens. Tissue culture studies were initiated to understand the structure-function relationship of cells.

Nematology

Nematology has been pursued at several institutions, notably Aligarh Muslim University (AMU) and IARI. Besides studying the systematics and structural biology of nematodes, the AMU scientists have carried out extensive studies on the nematodes associated with economic crops and the nematode vectors of viral diseases. The study on predatory nematodes--the mononchs--has received world wide attention. As these predatory nematodes feed voraciously on species of plant parasitic nematodes, they could be valuable in developing a biological control strategy.

Fishes and Fisheries Research

Fisheries research has gained special importance with the establishment of the Central Marine Fisheries Research Institute (CMFRI) at Cochin, Central Inland Fisheries Research Institute (CIFRI), Barrackpore, and some other institutes that are solely dedicated to research and training in this field. Important additions to our knowledge have been made by the scientists working at various fisheries institutes and universities in India on reproduction (Delhi, Nagpur and Visva Bharati), genetics (MKU), breeding and increased productivity (Barrackpore) . A number of indigenous fishes were identified and their physiology and reproductive patterns were studied in depth.

Aquatic ecosystems, including wetlands and coastal ecosystems, are important biologically, as they are among the most productive. They are also very prone to human disturbance, which is the largest single cause of biodiversity losses. In this context, the research being carried out at various universities and institutes, such as the Department of Aquatic Biology and Fisheries, University of Kerala, and NIO, Goa, has far-reaching economic implications. Air-breathing fishes such as *Anabas testudineus*, *Clarias magur*, *Heteropneustes fossilis* and *Periopthlamus vulgaris* among others, living in the swamps and poorly oxygenated marshy waters of North Bihar, have been studied in great detail at the Department of Zoology, Bhagalpur University. These studies have traced the likely evolutionary history of the early air-breathing vertebrates. Basic studies at the

Madurai Kamaraj University (MKU) of limnetic energetics using predictive models, has led to easier ways of arriving at answers to a number of problems in bioenergetics of aquatic systems.



***Tirumala limniace leopardus* (Butler).**

Oceanography

Oceanography has been a part of Indian science for the past two centuries. A number of expeditions were undertaken during the twentieth century to collect data on marine life. The international Indian Ocean Expedition of 1960s collected copious data on the physical characteristics of the Indian Ocean and its rich marine fauna. Scientists of the NIO have collected an enormous amount of scientific data on the biological life chain in the Indian Ocean. Several Indian expeditions were also conducted to collect the fauna of Antarctica.

Ethology and Sociobiology

Scientists at the University of Jodhpur, MKU and Indian Institute of Science (IISc), Bangalore, have made significant contributions to the field of animal behaviour. Desert rodent behaviour and adaptations were the subjects of special study at Jodhpur. Extensive behavioural studies of bats in relation to hibernation, foraging and mutual entrainment of biological clocks by means of social cues and loss of entrainment by exposure to continuous light, have been carried out by chronobiologists at the Department of Animal Behaviour and Physiology, MKU. The Chronobiology Laboratory at MKU was also instrumental in discovering that the menstrual cycle in the human female is not coupled to the sleep-wake clock under prolonged social isolation. A Chronobiology Laboratory has been set up at the Jawaharlal Nehru Centre for Advanced Scientific Research (JNCASR), Bangalore, to investigate the circadian rhythms in fruitfly and carpenter ant.

The biologists of the Centre for Ecological Sciences (CES) at IISc have contributed significantly to our understanding of social organization, division of labour and evolution of insect societies, particularly those belonging to the order Hymenoptera. They have conducted long-term studies on Indian species of ants, bees and wasps. Some of the significant new findings arising out of these studies include behavioural caste differentiation among morphologically identical members of wasp colonies, pre-imaginal caste bias in a primitively eusocial wasp and the role of nutrition in caste determination. The most significant contribution has been to demonstrate the inadequacy of genetic theories for the evolution of eusociality and the development of a new class of theories for understanding the origin and evolution of social life in the order Hymenoptera. This work has resulted in over hundred technical publications and has culminated in a monograph entitled *The Social Biology of Ropalidia: Towards Understanding the Evolution of Eusociality* to be published by Harvard University Press. Other

areas of study in this school include the social behaviour of the Asian elephant culminating in an authoratative work *The Asian Elephant*, published by Cambridge University Press and investigations on plant-animal interactions.

Entomology

Pioneering work in entomology, especially insect-plant relationships, have been carried out in various laboratories in the country. Sustained research in biosystematics and ecology of thrips (Thysanoptera), chemical ecology and cecidology carried out in Entomology Research Institute, Loyala College, Chennai. The Division of Entomology, IARI, and Delhi University (DU) addressed to the study of physiology and mode of action of insecticides and the biochemical basis for host selection by insects, insecticide resistance in mosquitoes and physiology of insects have been studied at DU. An entire School to study Himalayan insects was set up at St. John's College, Agra. The work of this School is internationally recognized. The FRI at Dehra Dun, has a large collection of insect pests that damage forest trees and seasoned wood. It also has an extensive collection of Indian termites and locusts made by eminent zoologists like M.L. Roonwal.



Photo: Biodiversity India Newsletter, Dec 2000

Rana sp., a species common in the forests of Assam and Meghalaya, yet undescribed.

Endocrinology

A number of significant additions to our know ledge of endocrinology and reproductive bio logy have been made in various universities and institutions in India. To name a few DU (M.R.N.Prasad and his students), Punjab Agricultural University (Ludhiana), Visva Bharati University (Santiniketan), CDRI (Lucknow), AIIMS (Delhi), National Institute of Health and Family Welfare (Delhi), National Institute of Immunology (NII, Delhi), IISc (Bangalore) and the Institute for Research in Reproduction (Mumbai). Studies ranging from the basic structural and physiological aspects of reproduction in lower vertebrates to contraceptive development for women and men, indicate the importance of this field of research. The inverse relationship between pineal activity and gonadal development was shown in tropical lizards. Scientists at the BHU elucidated the role of the thyroid gland in the mediation of the sexual cycle of a number of species of birds. These studies for the first time emphasized that the thyroid-gonadal interrelationships were essential regulatory components of animal biological cycles. Research conducted at Calcutta University clearly reveal that in birds, unlike mammals and other vertebrates, true insulin deficiency syndrome is not observed in a number of species. The avian endocrine pancreatic beta cells (which are the source of insulin secretion) are not vulnerable to the action of cytotoxic agents. Certain critical factors like high glutathione content, high somatostatin and elevated APP values may play significant roles in preventing diabetogenesis in birds. This knowledge can be used in future to work out better modalities of diabetic treatment in humans. The thyroid gland is now recognized as the mediator in the pathway, linking environmental signals, such as photoperiod, rainfall and humidity, to the control of gonadotropin-realeasing hormone (GnRH) neurons. Studies on the qualitative and quantitative aspects of spermatogenesis in various vertebrates such as bird, sheep, goat and buffalo have shown that their reproductive efficien-

cy is greatly affected by the degeneration of germ cells at various stages of their development and differentiation.

Applications of DNA Finger Printing: Significant contributions were made to understand chromosomal basis of sex determination in over 200 species of insects and Arachnids by scientists at BHU under the leadership of S.P. Raychaudhuri and at Delhi University students have continued the work at BHU, Kolkata and Hyderabad. The Bkm–derivel probe from the banded krait (snake) has been a landmark discovery at CCMB (based on the initial work done at BHU and Edinburgh). This probe has been extensively used in the development of an indigenous method for DNA fingerprinting for forensic investigations, solving paternity disputes and verification of seed stocks. A Laboratory for the Conservation of Endangered Species is being set up at Hyderabad by the Centre for Cellular and Molecular Biology (CCMB) in collaboration with the Nehru Zoological Park, Hyderabad, and the Government of Andhra Pradesh. This institute will create germplasm and tissue banks of endangered species, and carry out research in the areas of *in vitro* fertilization, artificial insemination, cloning and molecular breeding of endangered species such as lions and tigers. Scientists at the National Institute of Immunology (NII) and the Cenre for DNA Fingerprinting and Diagnostics (CDFD), Hyderabad have developed novel oligonucleotide probes foir DNA finger printing to uncover intra- and intersequence variability in the water buffalo, cattle, sheep and goats, and the one-horned rhinoceros (*Rhinoceros unicornis*) and the endangered swamp deer *Cervus durauceli branderi*. The unique species-specific cloned probe for the rhinoceros is useful for ascertaining the origin of biological tissues including those in the horn, in the event of poaching. Work has been initiated on the study of molecular profiles of the Mustelids, Viverids and Herpesids that include martens, badgers, otters, civets and mongooses of India. The objective is to understand their relationships, species delimitations and conservation status.

Protection of Wildlife

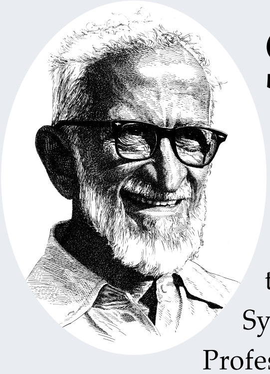
India has a very rich wildlife but the exponential growth of human population had an adverse impact on their population levels as also on their distribution. By 1986, India had only 6,15,095 sq. km area of wildlife habitat left, out of the orginal 30,17,009 sq. km., a loss of almost 80%. At the current rate of deforestation, about 5–10 per cent of the closed tropical forest species will become extinct per decade, i.e., about 100 species a day. The protection and nurture of wildlife has been recognized as an important function of the Ministry of Environment and Forests (MOEF), Government of India. The



Photo: Wildlife Instt of India, Annual Report, 1999-2000

Barred jungle owlet.

MOEF has set up protected areas in the form of sancturies, national parks and biosphere reserves to protect wildlife *in vivo* (see chapter on MOEF). The Ministry, in 1982, set up the autonomous Wildlife Institute of India at Chandrabani, Dehra Dun, with the mandate to strengthen wildlife conservation by providing trained professionals as wildlife scientists and managers and by making available scientific information. Towards this end the Institute conducts regular postgraduate and in-service, long- and short-term courses. The Institute has elaborate field-based



Salim Moizuddin Abdul Ali (1896- 1987) was born in Mumbai and had his early education at St.Xavier's High School and St.Xavier's College there. He was trained in Systematic Ornithology under Professor Erwin Stresemann at Berlin University Zoological Museum, 1929-30. Since then he went on ornithological expeditions to most of the unexplored and little known parts of the Indian subcontinent including the Western Himalaya, Sikkim, Bhutan and Arunachal Pradesh; also in Western Tibet and Afghanistan. He also studied birds in other neighbouring countries such as Myanmar and Malayasia as well and published numerous papers in scientific journals. The areas of special interest included zoogeography, ecology, conservation, bionomics of Indian birds. His surveys and individual bird studies were examples of how much information can be obtained with minimum of equipment, a notebook and pencil, a pair of binocular and an alert, analytical mind. He was probably the only person who had travelled to all the obscure regions of the Indian subcontinent. His knowledge and experience were respected and his timely intervention saved, for instance, Keoladeo National Park and Silent Valley National Park. He was recognized abundantly for his works, Gold Medal of Asiatic Society, Sundarlal Hora Memorial Prize and C.V. Raman Medal of INSA, Padma Bhushan and Padma Vibhushan to name a few.



Salim Ali has written a large number of books on the birds of the Indian subcontinent. His book on *Handbook of the Birds of India and Pakistan* with S.Dhillon Ripley, in 10 volumes (OUP, 1968-74) is the most highly respected work on the subject. *The Fall of a Sparrow*, an autobiographical account, is a fascinating account of the person who was utterly dedicated to the study of birds. Salim Ali was associated with the Bombay Natural History Society for over sixty-nine years and the organization gradually became synonymous with him. It was his family and all he cared for . Salim Ali was was elected a Fellow of the Indian National Science Academy in 1958.

Sketchs: V.N. O'Key (Salim Ali), CEE's NatureScope India (hornbill)

wildlife research programmes addressing biological, management and human dimension aspects conforming to national conservation priorities.

An important milestone in the field of conservation was the setting up of the Madras Snake Park in 1969 and the Madras Crocodile Bank Trust in 1974. In the mid -1970s, the Government of India set up the Indian Crocodile Conservation Project which has been instrumental in pulling back the once threatened crocodilians (gharial, mugger and salt water crocodile) from the brink of extinction. This project has also contributed invaluable knowledge of wildlife management, captive breeding and the training of personnel for research and administration to other similar projects.

Biodiversity and Conservation

Biodiversity is a buzz-word today. As defined by the Convention on Biological Diversity in Rio de Janeiro (1992), the term biodiversity is the *Variability among living organisms from all sources, including terrestrial, marine and other aquatic systems, and the ecological complexes of which they are a part; this includes diversity within species, between species and of ecosystems*. In other words biodiversity is the variety of life-forms including their genetic make up and all kinds of their assemblages. Biodiversity

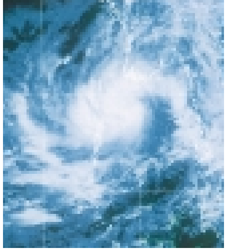
is important for economic benefits, ecological services, cultural-anthropological utility, recreation and epistemic utility.

One of the greatest needs as well as challenges in any country is inventorying and monitoring of biodiversity. For a country if India's size with its wide range of biogeographical zones, the task is stupendous. Besides the expertise available in BSI and ZSI, national institutes and non-governmental organizations such as the Bombay Natural History Society (BNHS), Mumbai, Salim Ali Centre for Ornithology and Natural History (SACON), Coimbatore, Wildlife Institute, Dehra Dun, and the universities, there is an important need to mobilize the talent avilable in colleges and schools for surveys and also involve remote sensing facilities for understanding the distribution of vegetation types and functioning of the ecosystems.

A leading biologist of the CES at IISc, Bangalore has launched the preparation of People's Biodiversity Registers (PBRs) sponsored by the WWF-India to record folk knowledge and practices of conservation and uses of living resources. It was envisaged to prepare PBRs between 6-15 village clusters each in the six states of Assam, Bihar, Himachal Pradesh, Karnataka, Orissa and Rajasthan and one union territory -- Andaman and Nicobar Islands.

Another activity launched by the Indian Academy of Sciences, as a part of its initiative to enhance the quality of science education in India, was a project called 'Lifescape'. This came as a tribute to the great Indian naturalist Salim Ali on the occasion of his birth centenary. This movement was also nurtured by the CES with the aim of publishing illustrated accounts of 2,500-5,000 Indian species of microbes, plants and animals. The beneficiaries of these accounts are the students and teachers of biology who would be able to identify the species and use them for accurate observations, field exercises and conservation efforts.

The MOEF has initiated a project to prepare India's National Biodiversity Strategy and Action Plan (NBSAP), supported by the Global Environment Facility (GEF) through UNDP. A Technical and Policy Core Group ((TPCG) consisting of experts from various fields and different parts of Indian from both government and outside has been constituted, with a representative of the NGO, Kalpavriksh, as the coordinator. Administrative coordination will be handled by Biotech Consortium India Ltd. This will be the biggest ever environment and development planning exercise in scale and participation. Started in the 2000, NBSAP aims to produce a series of planning documents dealing with the conservation of India's biodiversity, sustainable use of its biological resources and equity, including decisions regarding access to such resources and the benefits accruing from them. The end result of this exercise will be a series of action plans at local, state, inter-state, eco-regional and thematic levels, each independent, and also culminating in a National Plan.



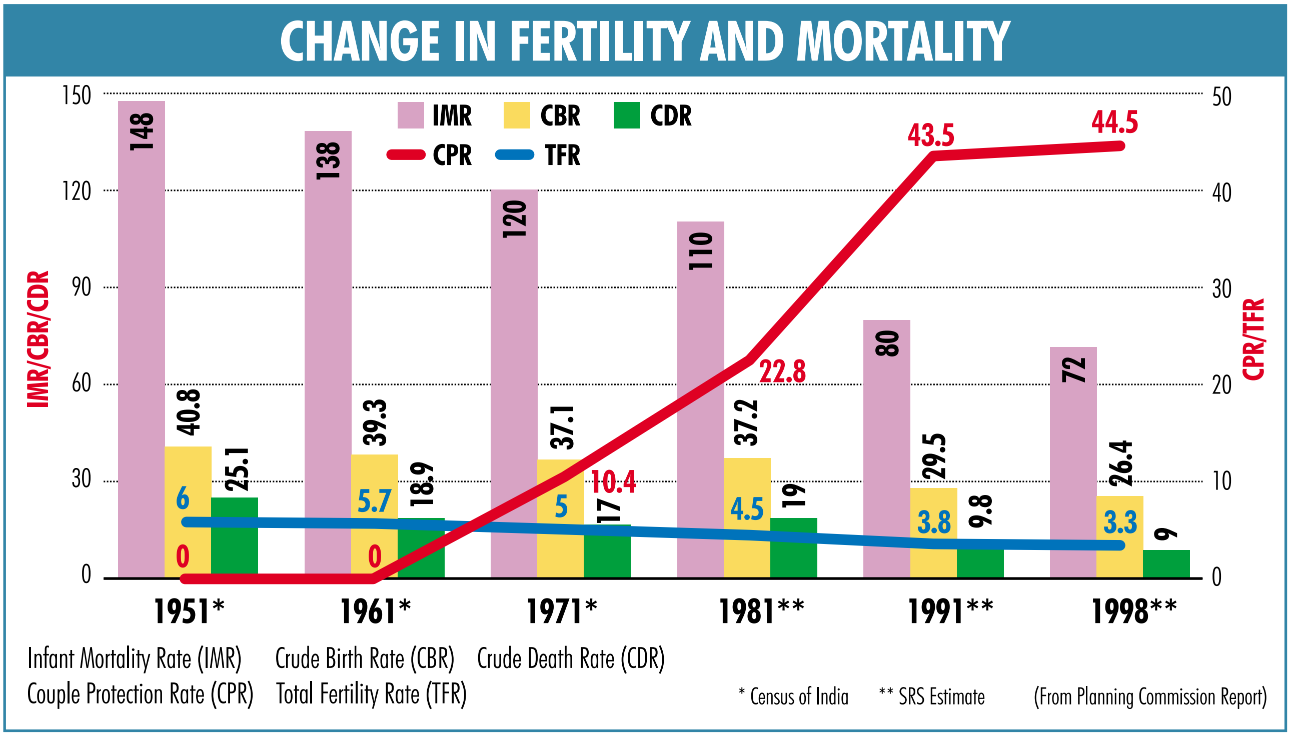
CHAPTER XVII

MEDICAL SCIENCES

Just prior to India's Independence, the then Government recognized that both the health care delivery services and medical education facilities, specially the postgraduate education were woefully inadequate for the needs of the country. Therefore, a Health Survey and Development Committee was appointed under the chairmanship of Sir Joseph Bhore in 1942-43. The Committee submitted its report in 1946. Among its many recommendations were two at the either end of the Health & Medical Education system, i.e. the establishment of Primary Health Centres (PHCs) and the creation of an apex institute for postgraduate education and research. It was, however, due to active efforts of the newly installed National Government that the first PHCs were established in 1952 and the All India Institute of Medical Sciences (AIIMS) in 1956. The existing district and provincial hospitals were progressively upgraded and the number of medical colleges increased. Selected bright young medical graduates were sent abroad to centres of excellence for training in the newly emerging disciplines like cardio-thoracic, plastic, neurosurgery and biomedical sciences. A number of young persons went on their own initiative. Back home they enucleated these specialities thus paving the way for achieving self-sufficiency in postgraduate teaching and training and in turn strengthening the research base.

> *SUKHAM SAMAGRAM VIJNANE VIMALE ĊA PRITISHTHITAM.*
>
> ALL HAPPINESS IS ROOTED IN GOOD SCIENCE.
>
> ĊARAKA

Health Care Delivery: At the time India won Independence, modern medical facilities were available mostly in our metropolitan and capital cities. District hospitals and in some places *taluk* hospitals existed but these were generally ill-equipped and did not provide any specialized services. The country is now served with a vast network of some 120,000 rural subcentres manned by one or two paramedical workers, approximately 19,000 PHCs, each with a staff of 15 paramedical workers and one or two medical officers, 3,500 community health centres having some speciality services and 30 in-patient beds. Each district has its own district hospital with a number of specialities -- medicine, surgery, orthopaedics, ENT, obstetrics and gynaecology, usually with over 100 beds with routine diagnostic laboratories. The country has over 160 recognized medical colleges and some in the private sector; new ones are being opened up. In addition there are a number of national institutes and speciality centres distributed around the country, staffed by specialists in all conceivable disciplines and equipped with the latest state of the art facilities.



How Has the Country Benefitted by These Developments ?

Undoubtedly, the answer is that these developments have resulted in a significant improvement in our health indices. Life expectancy at birth which was around 30 years in 1947, is already 60+. The infant mortality has come down from 140 to 72 per 1,000 live births and maternal mortality to 4.6 per thousand. No doubt, these are still unacceptably high for any civilized society but trends are towards continuous improvement.

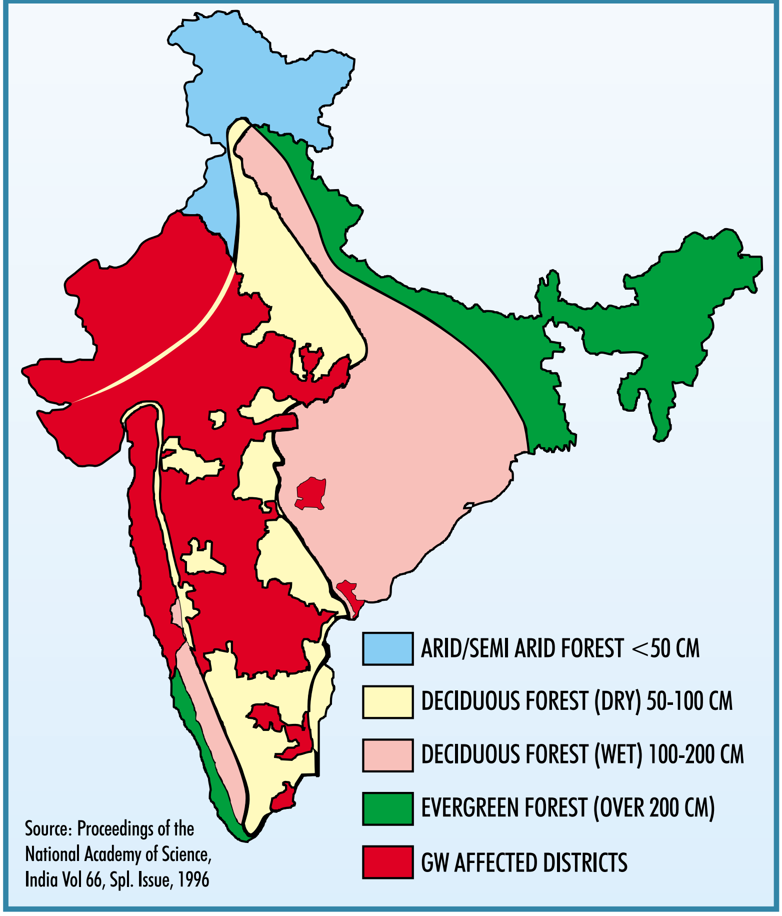
As a result of expanded immunization programme, there has been a progressive reduction in several infectious diseases. Smallpox has been eradicated, indications are that poliomyelitis may also be eliminated in near future. Already its incidence has been reduced to very low levels. Dracunculosis or guinea worm infestation, a curse in some parts of the country, has been wiped out. Since the introduction of oral rehydration programme, the mortality from childhood diarrhoeas and cholera has come down. There has been a perceptible reduction in the incidence of leprosy. Except for a minor outbreak, between August and October 1994 (affecting a limited geographical area and promptly brought under control), plague had virtually disappeared from the country. On the other hand malaria, kala-azar and some other vector-borne diseases which were fairly well controlled have once again become a matter of concern. Tuberculosis

Health Indices

	1951	1961	1981	1991	1995	2000
Crude Birth rate (per thousand)	40.8	39.3	37.2	29.5	28.5	26
Crude Death rate (per thousand)	25.1	18.9	5.0	9.8	9.2	9.0 #
Infant Mortality Rate	148	138	110	80	74	72*
Life Expectancy at Birth	32	41.3	56.0	61.2	-	60 +
Total Fertility Rate	6	5.7	4.50	3.80	3.40	3.3
Couple Protection Rate	-	-	22.8	43.5	-	45.0

In Kerala death rate is 6, Tamil Nadu and Karnataka 8, Andhra Pradesh 8.4.
*In Kerala the infant mortality rate is already down to 16 per 1,000. In Punjab, Maharashtra and Tamil Nadu this is around 50.

DISTRIBUTION OF GUINEA WORM IN DIFFERENT CLIMATIC ZONES PRIOR TO ITS ERADICATION





Guinea worm infection. (Source: Proceedings of National Academy of Sciences, India, 1966)

continues to affect two million persons causing 500,000 deaths every year. The situation is likely to become worse with the emergence of HIV/AIDS infection.

Extensive community studies revealed that approximately 170 million people were living in iodine deficient regions in the country. There was an alarming incidence of cretinism (3-5%), feeble mindedness (IQ 69 or below in 29%) and hearing deficiency (20%). With the introduction of universal iodination programme since 1986, there has been a perceptible reduction in iodine deficiency diseases, specially the severe variety of neonatal hypothyroidism with mental retardation and cretinism in badly affected regions of the country. Vitamin A supplementation programme has likewise started to show its beneficial effects for prevention of blindness. One could enumerate several such success stories. Yet the very fact that their root causes, poverty, lack of supply of safe drinking water, malnutrition coupled with unabated rise in population, high incidence of illiteracy and lack of adequate financial resources continue to bedevil the efforts, for which there are no S&T quick-fixes.

Similarly, if progress is to be measured by the proliferation of curative services, both in public and private sectors, India has made significant strides. Today we can proudly say that while at the time of our Independence we had no neurologist or neurosurgeon, no cardiologist or cardiac surgeon, only one cancer hospital worth the name, no specialized research-cum-service institute in any field of medical science, we now have all the facilities to train all our specialists in the country. A limited number of doctors from the neighbouring countries are also being trained. This facility could certainly be augmented if required. It can be stated without risk of contradiction that no patient needs to go abroad for any treatment or investigation. Renal transplant, cardiac transplant, liver transplant and bone marrow transplant have been successfully performed in India. Several centres can boast of results comparable to the best, be it for cancer, cardiac surgery or brain surgery. These services

are also provided to patients from the neighbouring countries. No doubt there is still a growing need for expanding these services quantitatively and geographically to make them available in every part of the country.

Medical Education and Research

In 1947, the country had only 16 medical colleges. While postgraduate speciality courses existed in most of these, unless one had a diploma (FRCS, MRCP, DCH, DO, DTM&H) from the Royal Colleges in the United Kingdom, a person was not considered adequately qualified for appointment as a specialist. Soon after Independence, there was a rapid growth of medical colleges all over the country. Today there are more than 160 such institutions with an annual enrolment of 16,000 students. To meet the growing needs of teachers for these colleges, as well as to create an environment for high-quality research, in 1956, AIIMS was established at New Delhi, by an act of the Parliament. Subsequently several such institutes like Post -Graduate Institute of Medical Education and Research (PGIMER), Chandigarh, The National Institute of Neurosciences and Mental Health (NIMHANS), Bangalore, and Sri Chitra Tirunal Institute for Medical Sciences and Technology, Thiruvananthapuram, were started.

> A STRONG S&T BASE IS CRUCIAL FOR SOLVING HEALTH PROBLEMS FACED BY A COUNTRY.

Compared to the scenario fifty years ago, medical research has certainly progressed. There are a number of institutes created by the Indian Council of Medical Research (ICMR), Council of Scientific and Industrial Research (CSIR), Department of Biotechnology (DBT) and other agencies which are actively involved in biomedical research. Many of these have set up centres to address problems of specific diseases such as the Malaria Research Centre, Delhi; the Cholera Research Centre, Kolkata; Tuberculosis Research Centre, Chennai; Vector Control Research Centre, Pondicheery; National AIDS Research Centre, Pune; Enterovirus Research Centre, Mumbai; and Leprosy Research Centre, Agra. Others are more broad-based like the Virus Research Centre at Pune, Institute for Research in Reproduction and Institute of Immuno-haematology at Mumbai, National Institute of Nutrition, Hyderabad and National Institute for Communicable Diseases, New Delhi. In addition to the ICMR, several scientific agencies have created research centres in specialized fields related to medical sciences like the National Institute of Immunology, New Delhi, National Centre for Cell Sciences, Pune; Centre for DNA Fingerprinting and Diagnostics, Hyderabad; National Brain Research Centre, Manesar; Functional Genomic Research Unit at Centre for Biochemical Technology, Delhi by DBT. Like-wise the Central Drug Research Institute, Lucknow; Indian Institute of Chemical Biology, Kolkata; Indian Institute of Chemical Technology and Centre for Cellular and Molecular Biology, Hyderabad; Industrial Toxicology Research Centre (ITRC), Lucknow; and Central Institute of Medicinal and Aromatic Plants, Lucknow; were established by the CSIR and Radio-pharmaceutical Centre and Cancer Research Centre by the Atomic Energy Commission. Thus a network of centres provide the infrastructure for medical research in the country. In recent years a few research centres have been established by major pharmaceutical industries and private organizations. Research is also being carried out at medical colleges and major hospitals in the country.

Even prior to mentioning some of the outstanding research findings of the Indian biomedical fraternity, it is important to explain the need for carrying out research. It has often been

stated that developing countries should not waste their limited resources on research since application of the already existing knowledge can solve many of their health problems. Experience has taught that whereas a strong S&T base is essential for survival of any country in this competitive world, it is even more crucial for solving the health problems predominantly faced by a country. Many diseases prevalent in the developing countries are of little interest to those in the developed world. World wide investment for research on health has been estimated to be about 30 billion dollars but only 5 per cent (1.6 billion) is devoted to the health problems of developing countries, which account for 93 per cent of the global burden of preventable mortality (measured in years of potential life loss). Out of $ 1.6 billion spent on developing country-oriented research 42% originated in the developing countries. It is now well established that the same disease prevalent in different parts of the world may not manifest identical problems, thus requiring locale-specific studies. Different ethnic populations, different genetic make up, varying socio-economic conditions or ecological environment modify the manifestations and therapeutic responses of a disease which prevent application of knowledge generated elsewhere to effectively deal with it. At the same time without indigenous competence in S&T, it is not possible to identify and utilize one's potential strengths taking advantage of the indigenous heritage and resources.

Community Based Research

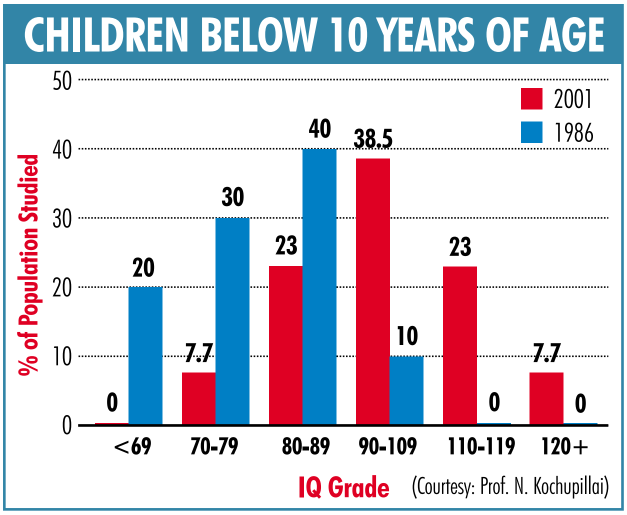
A number of important contributions of national and international significance have been made in recent years in every sphere of biomedical research. It is not possible to present a comprehensive account but a few are listed here to illustrate the above premises and to provide an idea of the range of activity. Thus amongst the community based studies one could unhesitatingly mention BCG trial, the oral poliovaccine studies, the iodine deficiency syndromes, the indigenously developed leprosy vaccine trials or the bio-environmental approaches to control malaria, epidemiological studies on cholera, malaria, filaria, leprosy, tuberculosis, cataract, coronary heart disease, stroke and cancer.

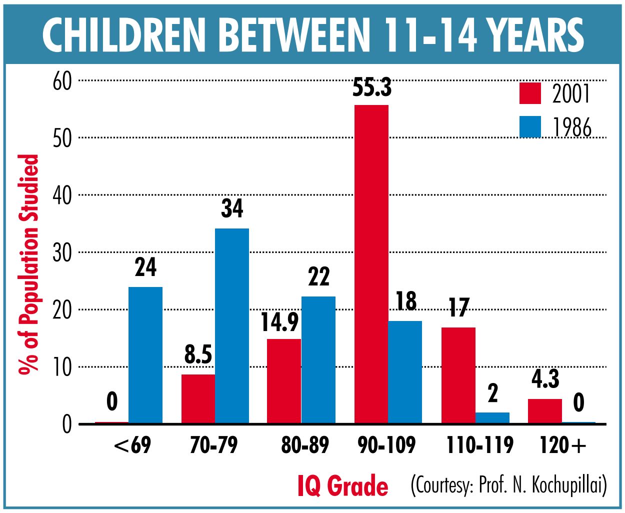
BCG Vaccine Trial: BCG had been universally acclaimed as the most effective vaccine available against tuberculosis. It was therefore accepted as a component of the Tuberculosis Control Programme from its very inception. However, doubts were soon raised about its efficacy in Indian population. The Tuberculosis Research Centre, Chennai, underlook a controlled field study in 1963. After an extensive carefully planned and executed study, it was established that BCG offered, i) low levels of protection in those aged 0-14 years, ii) no protection against the development of adult type bacillary tuberculosis, and iii) 20% protection against leprosy.

Oral Polio Vaccine Trial: WHO recommended three dose oral polio vaccine regime as a component of neonatal immunization programme. Unfortunately a number of children so vaccinated developed paralytic polio. Initially it was blamed on failure of cold chain. However, carefully carried out studies at Vellore and New Delhi unequivocally established the inadequacy of this regimen in India resulting in a radical change in the national programme which now seems to be producing desirable results.

Iodine Deficiency Studies: The prevalence of

> Paralytic poliomyelitis due to wild poliovirus infection has declined by more than 85% in most parts of India. More than 1,000 cases of poliomyelitis were annually reported from the city of Mumbai in the mid-1980s, in 1999, only 18 virologically proven poliomyelitis cases were reported from the entire state of Maharashtra of which 3 were from Mumbai. It is inspiring to note that Orissa has emerged as a polio-free state in the year 1999.





thyroid goitre in several regions of the country was well-known, however, its real gravity and etiopathogenesis were only brought to light with the utilization of the latest techniques of chromatography and radioimmunoassay by a team of researchers from AIIMS among some others. It was not the clinically obvious goitre but the incidence of cretinism, mental retardation and deaf-mutism that forced the Government to introduce universal iodination of the common salt as an imporant component of the National Iodine Deficiency Control Programme.

These three examples justify the need of carefully conducted research to solve national health problems rather than relying on knowledge generated elsewhere.

Bio-environmental Control of Malaria: Concerned with resurgence of malaria, increasing resistance to pesticides, rising cost and health consequences of newly developed ones, emergence of drug-resistant parasites, it became obvious that a new strategy need to be evolved to fight this menace. The Malaria Research Centre experimented with alternate regimes of bio-environmental control to suit the locale-specific requirements of different geographical sites in the country (for details see chapter on ICMR).

Kyasanur Forest Disease (KFD): A viral disease emerging as a consequence of deforestation in Karnataka was investigated by the National Institute of Virology, Pune. Not only was the virus identified but the puzzle of the origin and persistence of KFD virus in nature could be solved. A formalized vaccine was prepared.

Several such examples could be added but special mention may be made of the recent epidemiological studies on cholera epidemic caused by a new strain 0139 and the hepatitis E epidemic

Iodine Deficiency Disorders: Before and After Salt Iodination

Location	Prevalence of Goitre		% of Children with UIE < 5,ug/dl (Iodine deficiency)		% Hypothyroidism among school children		Neonatal Hypothyroidism; incidence per 1,000 births	
	Pre-Iodination	Post-Iodination	Pre-Iodination	Post-Iodination	Pre-Iodination	Post-Iodination	Pre-Iodination	Post-Iodination
Delhi	55%	21.8%	70%	0.64%	-	-	-	-
Gonda	70%	25.8%	>50%	0.75%	21%	<1%	75	9

Iodine deficiency disorders: Before and after salt iodination (Courtesy: N.Kochupillai)





Photo: N. Kochupillai

A case of endemic thyroid goitre (left) and mentally retarded progeny of a mother with severe iodine deficiency (right).

in Kanpur. Needless to reiterate, these studies could only be done in India, by scientists fully trained and equipped with latest techniques and technologies.

Basic Science Research

Demands of clinical work and urgent needs for tackling mounting public health problems did not permit as much attention to basic medical science research as requires. Nevertheless, a number of dedicated teams in practically every discipline of basic sciences — anatomy, physiology, biochemistry, microbiology, pharmacology, and pathology— advanced the frontiers of knowledge. In recent years, with the advent of molecular biology, immunology, biotechnology, genetics and genetic engineering there has been a rapid expansion in the base of biomedical research. Most of these researches have also been directed to address problems of national interest or areas of expertise of individuals or groups. Once again, the following have been cited as representative examples. This should not detract from the value of a large number of other works not included here.

Neurophysiological Investigations: The demonstration of well defined feeding and satiety centres in the hypothalamus of different species of animals, was followed by the studies on reflex mechanisms at the spinal cord and brain stem level, as also the role of feed back from the periphery. Comprehensive studies on the role of limbic system were carried out. Mechanism of sleep, wakefulness, and yogic state were explored.

J-receptors and Other Visceral Receptors: Spread over nearly five decades, persistent efforts at VP Chest Institute of University of Delhi, have revolutionized visceral physiology. Beginning with type B atrial receptors, successively, gastric stretch receptors, ventricular pressure receptors, J-receptors (juxta pulmonary capillary receptors), mucosal mechano receptors of the intestines and pressure-pain receptors of muscle were identified. J-receptors have acquired special relevance owing to the role they play in producing breathlessness and respiratory sensations leading to dry cough.

High Altitude Physiology: Soldiers guarding our frontiers at the inhospitable Himalayan peaks were found to suffer from life threatening pulmonary oedema and other physiological disorders. Pioneering researches by a group at AIIMS led by Sujoy B. Roy and his colleagues, as also by scientists from the Defence Research Laboratories and their collaborators have unravelled the underlying physio-pathology, leading to a management strategy practically abolishing the risks.

Nutritional Pathology: Starting with the initial studies of scientists at the Nutritional Research Laboratories, Coonoor, several major groups in the country at Delhi, Hyderabad, Vadodara,

Chandigarh, Varanasi, Vellore and Bangalore explored the various facets of nutritional deficiency in a variety of animal models and also human beings. These included morphological, biochemical and behavioural effects of not only protein-calorie malnutrition but also micro-nutrient deficiencies including iron, iodine, magnesium and various vitamins specially vitamin A, folic acid, Vitamin B 6 and B12. Simultaneously studies were carried out to evaluate the effect of corrective replacement at various stages of development. On the basis of these studies, national programmes were initiated to overcome their adverse effects on human health.

Immunology Approaches to Fertility Control: Population explosion being a subject of national concern, a variety of programmes and research strategies were initiated from time to time. One such novel approach was the immunological control of fertility using anti-hCG vaccine in females and anti FSH vaccine for males. At the same time another interesting approach was based on active immunization against riboflavin carrier protein to suppress pregnancy. Preliminary data and even clinical trials provided promising results. Unfortunately, there still remain several unresolved problems in applying these for control of fertility.

Molecular Biology of Malarial Parasite: A number of groups in the country specially those at IISc, Bangalore, AIIMS, ICGEB, NII, Malaria Research Centre (all at Delhi) and CDRI, Lucknow, have been exploring the various facets of molecular biology and biochemistry of malarial parasite specially *Plasmodium falciparum*. As a result of these studies efforts are going on to develop one or more vaccines. Major progress has been made in understanding the basis for chloroquin resistance. It was shown that the resistant strains of parasite have significantly higher levels of cytochrome P450. More recently, it has been demonstrated for the first time that intraerythrocytic stage of the malarial parasite degrades haemoglobin and utilizes the amino acids, thus generated for making its own proteins and also generate large quantities of heme sufficient to meet its own requirements. The latest discovery of fatty acid synthesis pathway in the malarial parasite and its inhibition by hydroxy-diphenyl ethers opens up new targets for drug development.

Professor V. Ramalingaswami

Professor V.Ramalingaswami (1921-2001), FNA, FRS, Past-President of INSA, was one of the most illustrious scientists of India, who gave a new direction to biomedical research. He initiated a paradigm shift by extending the sophistication of laboratory research to the bed-sides of the hospital and to the outreaches of the community in remote areas. His major scientific work consisted of studies on nutritional pathology, specially protein-calorie malnutrition, iodine deficiency disorders and nutritional anaemia. His studies on liver diseases in the tropics including Indian Childhood Cirrhosis, Non-Cirrhotic Portal Hypertension. The pathogenesis of so-called Nutritional Cirrhosis bear the stamp of scientific excellence. As Director of the AIIMS, he gave a new direction to education and as Director-General of the ICMR, provided new impetus to strengthen relevant and yet excellent research. He guided the national programmes and policies on health care delivery and research and generously extended his expertise to world bodies such as WHO, UNICEF and IDRC.

Clinical Research

Overburdened with demands for patient care services notwithstanding, astute clinicians have made significant dents in clinical research. Delineating the profile of known diseases affecting local population, defining their natural history, developing appropriate diagnostic and therapeutic

regimes (often at variance with the established practices), identifying new disease entities and syndromes have helped raise the standards of medical care and research. More recently, increasing collaboration between clinicians and biomedical scientists has provided rich dividends. Once again the following account is highly selective and may not necessarily represent the most outstanding.

Rheumatic Fever (RF) and Rheumatic Heart Disease (RHD): It was generally believed that RF and therefore RHD did not occur in tropical India. It was left to the astute observations of K.L. Wig to disprove this notion. The large number of cases of rheumatic valvular disease, which constitute a sizeable percentage of any cardiac-surgeon's work bear testimony to the continuing curse of these disorders. A syndrome of juvenile mitral stenosis has come to be recognized.

Indian Childhood Cirrhosis: As the name suggests this disease, affecting young children in India, attracted a number of studies by pathologists, nutrition experts and paediatricians. Even though its real etiology still remains a mystery, its morbidity and mortality have been markedly reduced.

Non-Cirrhotic Portal Hypertension: A clinical syndrome, quite different from the well known post-cirrhotic variety, was delineated, its pathology and clinical picture elaborated and appropriate therapy standardized as a collaborative effort of scientists from different centres in the country. It may be pointed out that studies by Professor V.Ramalingaswami and colleagues, established that the well-entranched term — Nutritional Cirrhosis, was a misnomer.

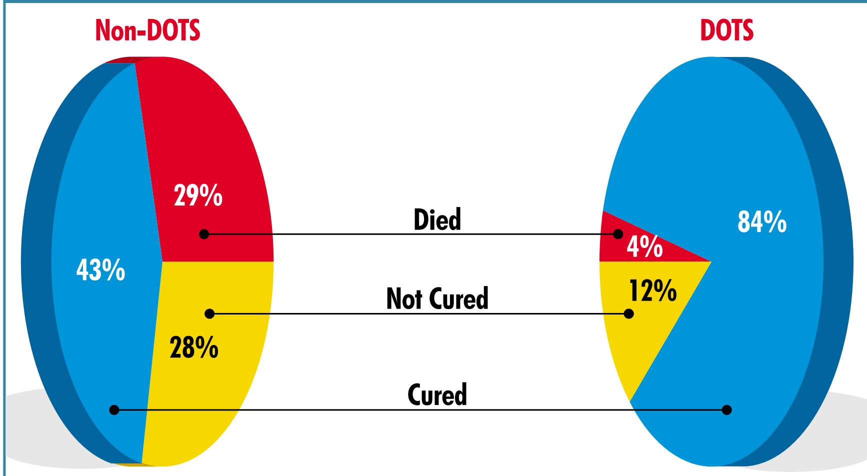
Endomyocardial Fibrosis: A devastating heart disease, usually terminating fatally has been the subject of careful studies. There is evidence to suggest that magnesium deficiency and higher levels of cerium may be responsible for this disorder. This finds support in an experimental animal model developed for further studies. The geochemical basis of this disorder has attracted wide scientific attention.

Tuberculosis including neurotuberculosis: The high prevalence of this disease with its protean manifestations, affecting practically every organ of the body, defying most conventional strategies to control it, has not surprisingly been the subject of many pioneering and now internationally recognized studies. The short-term chemotherapy and the supervised domicilliary treatment in place of sanatorial management are just two of these. All aspects of neurotuberculosis — pathology and pathogenesis, variety of clinical syndromes, diagnostic criteria and management strategies — have been critically documented using the latest microbiological, immunological and imaging techniques. Based on these studies medical treatment for intracranial tuberculomas has replaced the usual surgical management earlier advocated. These contributions have been internationally recognized as is obvious from the following statment, *In more recent years, the major contributions on both pathology and varied clinical manifestations of tuberculosis of the brain and spinal cord have come from workers in India,* ------- (R. Kocen in Infections of the Nervous System edited by P.G.E. Kennedy and R.D. Johnson,

ALL ASPECTS OF NEURO-TUBERCULOSIS — PATHOLOGY AND PATHOGENESIS, VARIETY OF CLINICAL SYNDROMES, DIAGNOSTIC CRITERIA AND MANAGEMENT STRATEGIES — HAVE BEEN CRITICALLY DOCUMENTED.

Butterworth, London 1987).

Leprosy: Beginning with the original work of Dharmendra and Khanolkar, a large number of past and present leprologists have contributed to a better understanding of this disease. These studies include clinical classification, immunology, pathology, reconstructive surgery and more recently development of at least two vaccines, which are by far the best so far available.



Directly observed treatment with short course chemotheraphy (DOTS) double cure rates in India—Findings of Joint Review (February 17, 2000)

Diarrhoeal Diseases: Ravaged by a host of pathogens resulting in loss of thousands of lives every year, especially children, biomedical scientists in India have continuously been engaged in research in these disorders. Just to name a few, the identification of cholera exotoxin, detection of a new cholera toxin, mapping the *vibrio cholera* genome, national surveillance of the epidemics, role of rehydration therapy and more recently development of a candidate vaccine which is already in limited phase II trial, deserve special mention. In addition to cholera other enteropathogens causing diarrhoea such as enterotoxigenic *E.coli*, shigellosis, amoebiasis, giardiasis and rotavirus have been thoroughly investigated. Recently two rotavirus candidate vaccines have been developed in collaboration with the US scientists under the Indo-US Vaccine Action Programme (VAP).





Leprosy: before (top) and after (below) combined chemotheraphy and immunotheraphy.

Lest it is understood that biomedical research in India has mainly concentrated on infectious disease, it may be mentioned that outstanding investigations have been carried on in other fields as well. Limitation of space does not permit a detailed account, but mention is made of epidemiology and etiopathogenesis of cataract, tobacco and arecanut related oral cancer and cervical carcinoma, coronary heart disease, atherosclerosis (clinical and experimental studies), stroke in young, neurolathyrism (including identification of its toxic factor BOAA from the grain legume *Lathyrus sativus*), veno-occlusive disease of liver (role of aflatoxins in its causation) and epidemic dropsy (caused by *Argemone mexicana* toxin).

Psychology: In the earlier years, like most other subjects, psychology education and research, followed the directions set in the West. However, it soon became obvious, that the subject is deeply rooted in the socio-cultural milieu of a community hence the 'tools' used for its study, cannot be directly adopted from other cultures. These were, therefore, modified tested and standardized for local use. Mention may be made of the work of Bhatia, Kamath and more recently of the work at PGIMER, Chandigarh, and NIMHANS, Bangalore, among others. Similarly the national needs dictated the direction of research in the fields of social psychology, industrial psychology, education psychology and anthropological studies on special population groups like tribals, or professionals like armed force personnel, or clinical psychology to evaluate patients with mental and neurological disorders and more recently persons at risk for sexually transmitted disorders and HIV/AIDS infection. This is not to say that work on more basic areas, including experimental psychology, cognitive science, or developmental and cross-cultural psychology of a very high calibre was not carried out.

Psychiatry & Mental Health: Research on psychiatry and mental health in India has progressed from hospital based descriptions of clinical syndromes to epidemiological and outcome studies. The clinical studies have contributed to the international recognition and acceptance of the syndrome of acute, brief psychoses which are seen to occur more in the Afro-Asian Region. Research on outcome of severe illnesses like schizophrenia have indicated more favourable outcome in 'developing' countries like India, attributed to the higher level of family and social support available in these societies.

The specific role of the social and cultural factors in depression has been studied, along with the study of suicide. Clinical and Biological Research on Depression and other disorders like obsessional disorders and groups of disorders like Substance Use Disorders has also been carried out, in the past few decades. Community based research on extending the mental health services to primary case has been processed at a few centres and is being applied as a service programme.

Neuroscience: A number of important contributions in the field of neurosciences — both basic and clinical have recently been summarized in a paper, *Neurosciences in India: An Overview (Annals of Indian Academy of Neurology*, **3**, 3–21, 2001) and hence only a brief summary is included here.

Some of the important contributions to neurophysiology and neuropharmacology are mentioned elsewhere. Major additions to knowledge have been made in the field of developmental neurobiology which include neuromorphological studies on developing embryo, both animal and human in respect to spinal cord, visual system and cerebellum. A large number of studies have dealt with morphological, biochemical and behavioural consequences of under-nutrition and malnutrition. At the other end a number of investigators have elucidated the biology of aging brain. Foetal neural transplant in rodents and monkeys provided valuable insights in its utility and pitfalls for replacing damage or degenerating brain tissue. Neurochemists in the country including B.K.Bachhawat put India on the international map. A major research outcome of his group has been tracing the biosynthetic pathway of cerebroside-3-sulphate and other enzymes associated with sulphate metabolism. For the first time it was established that deficiency of an enzyme (arylsulphatase A) was responsible for metachromatic leucodystrophy - an inborn error of metabolism. This tradition of pursuing neurochemistry is being carried forward. Similarly researchers at IISc and NIMHANS, Bangalore, and ITRC, Lucknow, alongwith a number of clinicians have done pioneering work on neurotoxicology specially in respect to neurolathyrism and pesticide toxicity. The underlying pathogenetic mechanism, including the role of cytochrome P450 in xenobiotic metabolism and detoxification of drugs

and toxins deserve special mention.

The clinical neuroscientists along with neuropathologists were primarily concerned with delineating the pattern of neurological disorders as seen in India, establishing the differences in their manifestations and natural history, laying down diagnostic criteria and guidelines for therapy. Not surprisingly most of the internationally acclaimed investigations belong to the areas of infective disorders and epidemiology. In addition, significant studies were made in the field of congenital malformations, epilepsy, stroke and subarachnoid haemorrhage and neural trauma.

Biotechnological Approaches for Development of Immunodiagnostics, Immunomodulators, Vaccines, Immunotherapeutics and Gene Therapy: Several diagnostic kits have been developed during the last few years. This became necessary not only because the imported kits were expensive but often these were not based on the prevalent strains of pathogens in the country. These include diagnostic kits for malaria, filaria, leischmania, hepatitis, HIV/AIDS, α-foetoprotein. A PCR based diagnostic kit for tuberculosis is in the final stages of validation.

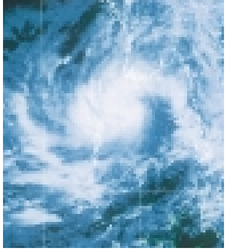
In addition to the leprosy vaccine mentioned earlier, hepatitis B vaccine based on indigenous efforts is already in the market. A candidate vaccine against cholera is currently in Phase II trial. Two rota -virus vaccines have completed Phase I trial and have been approved for limits Phase II trials. Work on candidate vaccines for Japanese encephalitis, malaria, tuberculosis and rabies is being pursued vigorously.

Miscellaneous

There has been renewed interest in scientifically establishing the value of traditional medicines, several of these are undergoing clinical trials. Thus a variety of uses of neem oil as a bactericidal, spermicidal and mosquito repellant have been established scientifically. Similarly the antioxidant, anti-inflammatory and anticarcinogenic properties of turmeric and curcumin have been evaluated. Some traditional health promoting practices like yoga and meditation, are being critically evaluated utilizing the latest scientific tools and techniques. At the same time as a result of researches in our laboratories, the country has developed indigenous capability to produce a number of bulk drugs and expensive imported drugs and make them available at affordable price by innovative process development e.g. AZT, vincristine and others.

At least a few biomedical devices, based on researches in the country, are already in the market. These include the well known Jaipur foot for amputees, shunts for treatment of hydrocephalus and an indigenously devised Tilting Disc Cardiac Valve and Spectra Oxygenator.

In conclusion, this very brief review should convince any one of the immense strides that medical science has made in India during the past 50 years. Compared to the developments in the 50 years preceeding Independence, there has been a quantum jump. Nevertheless, a great deal needs to be done if we have to meet the growing health needs of our people and share our knowledge with others, specially developing nations in this era of globalization.



CHAPTER XVIII

Pharmacology and Pharmaceutical Industry

India followed the British tradition of teaching Materia Medica as a comparatively minor subject to medical students till about 1940. The School of Tropical Medicine in Kolkata had created a Chair of Professor in Pharmacology for Col. Sir Ram Nath Chopra in 1922. The drug famine during the World War II brought the importance of pharmacologists in prominence and several departments of Materia Medica were upgraded to departments of Pharmacology with full time Professor as the head.

The growth of Pharmacology was very rapid after 1950 with opening of new medical colleges and developing post-graduate facilities at several centres. This was followed in due course with new institutions of Pharmacy and Veterinary Medicine. National laboratories such as Central Drug Research Institute (CDRI), Lucknow and R&D units of Pharmaceutical Industry (e.g., CIBA Centre, or those of Hoechst, Ranbaxy, Reddy's etc.) have also aided the process. The growth was substantially helped by return of many pharmacologists trained abroad; provision of fellowships by agencies like the Rockefeller Foundation and WHO for training within the country and abroad; establishment of specialized units or centres of advanced research by ICMR, CSIR etc.; and by visiting Professors from abroad. Thus the visit of Prof. Lewis to Seth GS Medical College, Mumbai initiated the development of the first Clinical Pharmacology facility of the country. Constraint of space will not permit a comprehensive review of the contributions made by Indian pharmacologists; only the major highlights have been summarised below.

Neuropharmacology

Several centres of excellence exist in the country. The investigators have used a variety of non-rodent and rodent animal species and routes of drug administration ranging from micro-iontophoresis to systemic routes. The parameters have varied from action potential of single neuron or biochemical parameters of *in-vitro* brain tissue to gross behaviour in normal animals. In some studies ablation and/or electrical stimulation of specific loci/centres has been undertaken.

Basic Neuropharmacological Studies:

Catalepsy: Acetylcholine, histamine, 5-HT, dopamine, GABA and prostaglandins have been shown to play a direct or modulating role in experimental drug induced catalepsy. A modulating role of 5-HT in Parkinsonism has been demonstrated.

Stereotypy: Stereotypy induced by amphetamine, apomorphine and other dopamine agonists and methylphenidate has been analysed in-depth in mouse, rat, mastomys, guinea pig and pigeon. Dopaminergic mechanism is more important in the mammalian species whereas non-dopaminergic mechanisms enjoy a major role in the pigeon.

Aggressive Behaviour: This behaviour is mainly modulated by dopaminergic (D2), adrenergic, serotonergic (5-HT2 and 3) and histaminergic (H2) mechanisms. Dopamine has an excitatory and 5-HT an inhibitory role. GABA and peptidergic systems are also involved in clonidine-induced automutilation.

Learning and Memory: Role of 5-HT (specially 5-HT2 and 5-HT3 receptors), dopamine, cholinergic (muscarinic) and NMDA receptors has been elucidated by utilizing a variety of experimental paradigms in rat and mouse, including experimental model of Alzheimer's disease.

Blood Brain Barrier: The regulatory role of histamine (H2 receptors) and prostaglandins has been established. The most important observation is transitory opening of the barrier by intravenous bolus of hypertonic saline. This has important clinical utility for delivering those drugs to the brain which do not easily cross the blood brain barrier.

Thermo-regulation: Indian studies were the first to demonstrate the involvement of a-adrenoceptor in thermo-regulation. Subsequent studies in several species (rat, rabbit, guinea pig, mastomys, and pigeon) have delineated the role of dopamine, histamine, opioid peptides, prostaglandins and histamine and species specificity of some of their effects. The receptor subtypes for dopamine, opioid peptides, 5-HT and histamine have been identified. The mechanism of LSD25-induced pyrexia has been analysed.

Central Cardiovascular Control: The regulation of blood pressure, heart rate and rhythm have been analysed to elucidate the role of various subtypes of adrenergic, cholinergic, 5-HT and opioid receptors and of nitric oxide. Their involvement in modulating the central cardiovascular effects of drugs has also been studied. Two important outcomes have been identification of the spinal cord and ventral medulla as important regulatory sites and targets for drug action.

Analgesia: The mechanism of action of narcotic analgesics and their neurotransmitter modulation has been studied. The involvement of opioid receptors, acetylcholine, dopamine, 5-HT (5HT1D) and histamine (H1) has been demonstrated. Opioids, prostaglandins and 5-HT are involved in stress induced analgesia. Analgesia by electrical stimulation of pretectal nuclei (SPA) utilizes multi-transmitter pathways involving opioid peptides, nitric oxide, acetylcholine, dopamine and nor-epinephrine.

Peripheral Markers: High affinity binding sites for 5-HT and dopamine exist in platelets. The dopamine D2 platelet receptor is valuable in monitoring progress and response to L-DOPA in the patients of Parkinsonism. Indian studies also highlight the utility of receptors for dopamine, Nitric Oxide (NO) on the polymorphonuclear leucocytes in patients of Parkinsonism, migraine, schizophrenia, depression and other CNS disorders.

Other Studies: Role of histamine H1 and H2 receptors and enkephalins in the CTZ and vomiting center has been analysed. LSD25 was shown to have potent anti-emetic activity. Dependence to morphine, cannabis, methaqualone and benzodiazepines has been extensively studied. Isatin (deoxindole) has been proposed to be a novel and important endocoid biological modulator in anxiety and stress.

THE INDIAN PHARMACEUTICAL INDUSTRY: A BIG GLOBAL PLAYER

Producer of largest number (about 350) of bulk drugs by any single country in the world. Major global supplier of generic drugs, targeting towards 10% of US generic drug market.

About 250 units have their own R&D Units recognized by the Government of India.

DEVELOPMENT OF NEW DRUGS:

The first major CNS active drug to be synthesized and evaluated in India was Methaqualone. Phase I study in normal volunteers was also done. Lack of familiarity with the patent procedures unfortunately led to its commercialization as a hypnotic by drug houses in UK and US. Subsequently, more coordinated R&D activity led to


Photo: H.Y. Mohan Ram

Curcuma longa (haldi). The rhizome is the source of curcumin, the natural orange-yellow food colourant, with potential uses in myocardial ishaemia and treatment of cancers.

the development and marketing of several CNS active drugs within the country. These include the antidepressants nitroxazepine (Sintamil®, CIBA) and centpropazine (CDRI); neuroleptic biriperone (centbutindole, CDRI); local anaesthetic bucricaine (centbucridine, CDRI; Centoblock® Themis); neuromuscular blocking agent chandonium iodide and standardized extract of neotropic *Bacopa monnieri* (CDRI; Memory Plus®, Nivaran). A metenkephalin analog (CDRI 82/205) is being developed as a potent analgesic.

New Animal Models

CDRI has developed a CNS screen with a battery of simple *in-vivo* tests for various CNS activities. It has screened about 4000 plants, several thousand synthetic compounds and over 500 marine products. A protocol has been standardized to study effects on cognitive behaviour of the rhesus monkey. A primate model of anxiety has been developed using sub-convulsive doses of metrazol in the rhesus monkey. CDRI has standardized the use of mastomys (*Mastomys coucha*) a new similar model, especially for studies on thermo-regulation and stereotyped behaviour. CDRI has also developed a single test for compounds effective in grand mal or petit mal epilepsy. Elsewhere in the country, a status epilepticus model has been evolved. Clonidine-induced automutilation has been developed as a model of clinical self-injury.

Cardiovascular Pharmacology

Besides the central cardiovascular control, other major areas include cardiac arrythmias, ischaemic injury, atherosclerosis and thrombosis.

Cadiac Arrythmias: Several models have been employed to define the role of adrenergic and cholinergic mechanisms. The ventricle has poor cholinergic innervation. Still the acetylcholine level falls further after vagotomy in all the species studied. The negative inotropic effect is exerted by inhibition of Ca^{++} channel activity. The classical anti-arrythmic agents decrease norepinephrine release in the myocardium. The β-adrenoceptor antagonists are most effective in blocking experimental arrythmias. Ajmaline has good anti-arrythmic activity.

Myocardial Ischaemia: The injury has been produced by isoprenaline, coronary artery ligation and by ischaemia-reperfusion in several species. The role of Ca^{++} in injury and the salvaging effect of calcium channel blockers has been shown in the reperfusion model. Protection has also been obtained with desimipramine and cardioselective α- and β-adrenoceptor blockers. Minoxidil protects by opening the potassium channels and acting as a α2 agonist in the isoprenaline model. Natural products coleonol, curcumin and picroliv also afford protection, besides the calcium channel blockers and β-blockers. Deleterious effect of thromboxane and protection with low dose of aspirin has been shown. Iloprost protects by increasing NO release and decreasing release of cytotoxic mediators.

Hyperlipidemia and Atherosclerosis: CDRI has developed sensitive acute and chronic models of hyperlipidemia in several species of laboratory animals. A standardized fraction of Gugulipid from *Commiphora wightii* has been marketed (Guglip®, CIPLA) and some synthetic analogues are under clinical evaluation. Clinically, lipoprotein(a) has

been shown to have a potent atherothrombogenic effect. A large pool of tryptophan concealed in normal low density lipoproteins (LDL) is exposed on the aqueous surface of LDL in diabetic patients.

Thrombosis: Two new thrombogenic factors modulating aggregation of platelets have been isolated from the serum. One is a low molecular weight fibrinogen-derived peptide and the other a β-globin gene related protein. Neutrophils play a pivotal role in thrombosis. Cycloxygenase inhibitors and NO releasing compounds afford protection. Gugulipid, curcumin and anti-implantation agent centchroman prevent platelet aggregation.

New Animal Models: A model of frostbite has been developed in rat. Good experimental models of atherosclerosis and myocardial infarction have been standardized in the rhesus monkey. In addition acute (constriction of aorta above renal arteries) and chronic (spontaneous) hypertension has been produced in the same species.

Development of New Drugs: Detailed pharmacology of cardenolide, peruvoside, from the apocynaceous plant, *Jhevetia neriifolis* was studied in India but the drug was commercialized in Germany. Asclepin is another potent and safe cardenolide. Gugulipid became the first Indian natural product to be licensed in Europe after being marketed in India.

Endocrinology

The major activity in this area has been in the fields of reproductive biology and diabetes.

Reproductive Biology

The main interests have been in understanding the mechanism of action of clinically used contraceptives and in the development of novel contraceptives.

Basic Studies: The physiology of fallopian tubes, cervix and the uterus and their role in ovum transport, fertilization and peri- and post-implantation events has been studied. The steroidal contraceptives inhibit steroidogenesis, leading to suppression of hypothalmo-hypophyseal system

Photo: C.M. Gupta



A few drugs developed by CDRI are manufactured and marketed by private companies.

and inhibition of ovulation. The anti-implantation agents, like centchroman, mainly inhibit decidualization, alter implantation associated biochemical markers and suppress the local inflammatory reaction. In the male, the site and mechanism of action of antispermatogenic agents and heavy metals like cadmium have been studied. The functional maturation of epidydimis has been shown to be an endocrine-mediated event, but some paracrine factors from testis are also involved.

Studies on Intrauterine Devices (IUD): Prolonged stay of (IUD) such a copper-T is devoid of noteworthy histological or biochemical changes in uterus or fallopian tubes. A reduction in uterine fluid leads to a many-fold increase in protein, urea and uric acid content. These, perhaps, make the milieu hostile to implanting blastocyst. IUD-induced bleeding is shown to be multifactorial.

Anti-implantation Agents: India is a global leader in the development and use of non-steroidal anti-implantation drugs. Ormeloxifene (Centchroman, CDRI) is a potent anti-estrogen and weak estrogen and hence a selective estrogen receptor modulator. It inhibits decidualization response to blastocyst, leading to implantation failure. After extensive clinical trials it is now marketed as a weekly oral pill in India (Saheli®, Hindustan Latex and Centron®, Torrent) and licensed abroad. Other indications

India Aids War Against AIDS

The fight against HIV AIDS plagued by exhorbitantly high price of drugs marketed by MNC cartels.

CIPLA, a Mumbai based Indian company, produced Nevirapine made it available at 1/6th the prevailing global price. It is currently also producing Lamivudin, Stavudine and Zidovudine.

Other Indian companies joining the crusade to produce full range of anti-AIDS drugs and with substantial export include Orchid Chemicals & Pharmaceuticals, Aurbindo Pharma and Ranbaxy Laboratories.

include advanced breast cancer and dysfunctional uterine bleeding. Its ability to increase bone calcification could be beneficial in osteoporosis.

The neem tree (Azadirachta indica). Besides azadiractin, an antifeedant agent for controlling insects, the neem extract has spermicidal and hypoglycaemic properties

Immunocontraception: Clinical studies with β-HCG tetanus toxoid vaccine developed at the National Institute of Immunology, despite variable protection, have indicated the feasibility of immunocontraception. Other potential leads include peptide sequence of GnRH, zona pellucida glycoprotein 3(ZP3) and riboflavin carrier protein (RCP) in the female and anti-FSH vaccine in the male.

Spermicides: The interest has increased due to the possibility of their having anti-HIV action also. CDRI is completing multi-centric Phase III study of *Sapindus mukorosi* based cream Consap. *Azadirachta indica* formulations are being developed by National Institute of Immunology (NII) and Defence Research Laboratories at Delhi.

New Drugs and Devices: Centchroman is being marketed as a weekly oral contraceptive and for advanced cases of breast cancer. *Plantago ovata* based cervical dilator (Isaptent, CDRI; Dilex-C®, Unichem) is useful in MTP and related procedures

Animal Models: WHO has accepted the CDRI



Photo: H.Y. Mohan Ram

bioassays for contraceptives as Mandatory Bioassays (MB). A monkey model of IUD bleeding has been developed.

Diabetes

Basic Studies: Pancreatic β-cell has a common binding site for glucose and alloxan. Functions of insulin receptor in liver and RBC have been studied. Aspirin delays the onset and progression of diabetic cataract. Glucose has antagonistic effect on opioid receptor. Metenkephalin increases blood glucose level and the effect is reduced in streptozotocin diabetic rats.

New Drugs: A benzoquinazolone (Centpiperalone, CDRI) was dropped due to side effects after Phase II clinical trial. Standardized *Pterocarpus marsupium* extract was effective in ICMR multicentric trial. Some active constituents have been identified. Plants effective in streptozotocin model include neem (*Azadirachta indica*), bitter gourd (*Momordica charantia*), Chirayita (*Swertia chirayita*) and Jamun (*Syzigium cumini*). Several other plants have been reported active in the alloxan model.

Gastrointestinal Tract

Hepatoprotective Agents

An *in-vivo* model for hepatic drug metabolism utilizes estradiol-induced vaginal cornification as the indicator. CDRI has standardized a comprehensive *in-vitro, ex-vivo* and *in-vivo* battery of tests to evaluate hepatoprotection. Eleven hepatotoxins (including ethyl alcohol and rifampicin) and 21 biochemical parameters are used. A major outcome has been development of Picroliv (CDRI), a standardized iridoid glycoside fraction of *Picrorhiza kurroa*. Phase III clinical studies are being initiated. Other plants shown to have significant activity include *Andrographis paniculata, Ricinus communis* and several species of *Phyllanthus*.

Peptic Ulcer

Basic Studies: Centrally mediated cytoprotection is afforded by dopamine (DA2), PGE2, GABA and endorphins, TRH and histamine (H1) having an opposite effect. Peripheral protection is afforded by β-adrenergic blockers, estrogen and adenosine (A1) receptor agonist. Morphine has been reported both to inhibit and to aggravate and μ and κ receptors have been implicated. Histamine and Ca^{++} influx play a major role in ulcerogenesis.



Photo: H.Y. Mohan Ram

A twig of varuna or barna (Crataeva nurvala). The bark is effective in dissolving stones in the urinary bladder.

New Drugs: Intensive study has been done on fruit pulp powder of edible banana (*Musa spp*). It affords protection by increasing mucosal resistance thus strengthening mucosal barrier. The DNA content of gastric juice is decreased. Protection has also been reported with several flavonoids, ursolic acid, nimbidin, tea and an Ayurvedic powder formation *Tamrabhasma*.

Other Studies

Mastomys oesophagus and rat jejunum, have been used for assay of 5-HT (5-HT2) and acetylcholine respectivity. Potent spasmolytic activity is reported in himachalol and related sesquiterpenes from *Cedrus deodara*, and coumarins clausmerin from *Clausena pentaphylla* and angelicin from *Heracleum thomsonii* respectively.

Chemotherapy

Diarrheal Diseases: An experimental model of cholera has been developed in infant rabbit. The role of ORS in treating diarrhoeas has been established. A new serotype (*Vibrio cholerae* 0139) has been







Photos: H.Y. Mohan Ram

Top: Commiphora wightii, the source of guggul, an Ayurvedic medicine used by Suśruta for reducing body fat. The shrub has a green trunk with a fleshy bark. When incised, a yellow fluid oozes out. It dries up into a brown mass of oleo-resin gum; Middle: Withania somnifera (ashagandha), called the 'Indian ginseng' is used in hundreds of formulations in traditional Indian medicine; Bottom: Bacopa monneri, a weed of wetlands, it is the source of Memory Plus® and Nirvana.

characterized. New Indian vaccines for cholera and rotavirus are under clinical evaluation.

Leishmaniasis: Indigenously developed liposomised amphotericin B is safer and shortens the duration of therapy. Similarly, 20 days combination therapy of aminosidine + sodium stibogluconate is as effective as over 40 days treatment with the latter alone. A primate model has been developed in *Presbytis entellus*. New IFA- and ELISA- based diagnostic tests have been developed (CDRI) and commercialized.

Mycobacterial Infections: Clinical trials have been conducted to establish optimum Multiple Drug Therapy (MDT) regimens for leprosy and tuberculosis. Therapeutic utility of *Mycobacterium* (strains – ICRC, Cancer Research Centre; w, NII) vaccine in leprosy has been shown. CDRI non-pathogenic *Mycobacterium habana* based vaccine awaits evaluation.

Mycotic Infections: In-vivo primate model has been developed to test anti-fungal drugs. An antifungal antibiotic Hamycin® (Hindustan Antibiotics Ltd.) one of the first one to be developed in India has been commercialized.

Malaria: Plasmodium knowelsii model has been standardized in the rhesus monkey and has been used to demonstrate protective effect of γ-interferon. Artemesinin artether has been developed from *Artemisia annua*, a chinese traditional medicinal herb (CDRI and CIMAP) and marketed (E-Mal®, Themis) for resistant or virulent falciparum infection. A safer anti-relapse synthetic agent (Bulaquin, CDRI) has also been commercialized (Aablaquin®, Nicholas Piramal).

Filaria: A primate model of human disease has been established in *Presbytis entellus*. Phase I-III WHO studies with Ivermectin and Phase III studies with low dose diethylcarbamazine (DEC) have been undertaken. Clinical studies have been done with DEC enriched salt and are in progress with the new macrofilaricidal amocarzine. Multicentric clinical (ICMR) and experimental evaluation of macrofilaricidal activity of the bark of *Streblus asper* is in progress.

Global Presence of Dr. Reddy's Laboratory

It is today India's most vertically integrated company with an annual turnover of US$ 100 million (bulk drugs 36%, formulations 64%). It currently has marketing presence in 40 countries on all continents including USA and European countries.

Oral antidiabetic insulin sensitizers licensed to Novo Nordisk in 1998 are now in Phase II clinical trials.

The antidiabetic and dyslipidemic compound recently licensed to Novartis for US$ 55 million.

Medicinal Plants

The initial emphasis on validation of traditional claims has shifted to correlate activity with chemical constituents and GCP norm clinical studies with standardized preparations. Highlights not mentioned in the preceding sections are summarised below.

Broad Based Screening: CDRI has used over 100 *in-vitro* and *in-vivo* tests for broad-based screening of over 4000 plants and 600 marine organisms / 15% of the samples had significant activity providing leads for new drugs, pharmacophores or pharmacological tools. A high throughput screen has now been added. More limited programmes existed at RRL, Jammu, the CIBA and the Hoechst Research Centres, Mumbai.

The ICMR Initiative: ICMR is utilizing the 'Ward to Laboratory' approach in selected diseases with chosen products. The studies have demonstrated advantages of *Kshara-sootra* over surgery in anal fistula and anti-diabetic activity of the wood and bark of the leguminous tree bijasal or bijasara (*Pterocarpus marsupium*). Standardized preparations are ready for commercialization. Other studies are in progress.

New Drugs: Mention has already been made of Peruvoside, Gugulipid, Isaptent, Artether and *Bacopa monnieri*. RRL Jammu has commercialized

Growth of Pharmaceutical Industry since 1950 in India

Parameter	Years		
	1950	1980	1990
Manufacturing Units	200	6400	23800
Investment	50m	6000m	21500m
Production	100m	14400m	170260m
Export	No Data	460m	53700m
Import	—	1130m	24580m

(The figures are number of manufactures and millions of Rs. for other parameters)

Boswellia serrata gum resin as NSAID (Sallaki®, Gufic). It is also hypolipidemic. The anti-parkinsonian *Mucuna pruriens* (Zandu) and immunomodulator from the plant guduchi (*Tinospora cordifolia*) (Seth GS Medical College, Mumbai) have also been marketed. The absence of a patent led to several pharmaceutical companies marketing products based on CDRI's work on psoralen for treating leucoderma.

New Leads: Coleonol (Forskolin) from *Coleus forshkoli* is now a major experimental tool. Piperine as a "bio-availability enhancer" has great potential for use with drugs needing prolonged use or having low safety margin. Curcumin, from the turmernic plant besides being NSAID and anti-carcinogenic, has multifaceted actions. The clinical utility of *Ocimum sanctum, Withania somnifera, Tylophora indica* and *Terminalia arjuna* needs further evaluation. Several plants have facilitated adoption to high altitude (DIPAS, Delhi). The therapeutic utility of common food items like onion, garlic, ginger, fenugreek, and tea is receiving increasing attention. Interferon-like activity has been demonstrated in several plants.

Clinical Pharmacology

Even though activity in clinical pharmacology was initiated at Seth GS Medical College, Mumbai in 1960, real spurt has occurred during the last two decades. Many colleges now have faculty positions, few have postgraduate programmes and some centres of excellence have

developed. The major areas of activity are summarized below:

Clinical Trials: The initial studies were Phase III studies with drugs already marketed abroad. These have continued. The development of new drugs in the country has generated expertise in Phase I and II studies as well. Several centres are involved in Phase II and III trials of standardized traditional drugs. Lately Phase IV (Post marketing surveillance) has been initiated for some drugs developed in India (e.g. Centchroman).

Bioavailability: Several centres undertake bioequivalence studies but a few perform bioavailability of new drugs and formulations. New models are also being developed.

Pharmacokinetics: Studies have been done on a few drugs developed in India (e.g. Centchroman). The altered pharmacokinetics of known drugs in diseases like diabetes, hepatic, renal, cardiac and thyroid disorders, tuberculosis etc. has been extensively studied. The effects of age, genetics, time of administration have been studied. In addition, food-drug and drug-drug interactions (e.g. between oral contraceptives and antimalarials or antitubercular drugs) have received adequate attention.

ADR Monitoring: Multicentric programmes to monitor adverse drug reactions were initiated by the Drug Control Organization as well as ICMR. ICMR will soon initiate Phase II of the programme with a wider coverage and more focussed proforma.

Other Studies: These have included therapeutic drug monitoring (anti-convulsants and lithium), pharmaco-dynamic studies and survey of drug prescribing and utilization patterns to develop pharmacoeconomics.

Other Studies

Venoms and Toxins: Pharmacology of venoms of several species of scorpions including *Buthes tamalus*, *Heterometrus bengalensis*, and *Isometrus thivaitesi* has been studied and responses shown to be mediated by phospholipase, 5-HT, histamine and prostaglandins present in the venom and by the release of autacoids like bradykinin. The toxic factor(s) in venoms of wasp *Vespi cinicta* (vecikinin), centipede *Scolopendra Subspinipes* (Toxin S), catfish *Heteropneustes fossilis* (HREF) and fish *Spherodies oblongus* etc. have been isolated and their actions analysed. Snake venom neutralizing activity has been observed in extracts of of plants such as *Hemidesmus indicus* and *Pluchea indica*.

Anti-inflammatory agents: CDRI has developed the carragenin oedema test in mice as a screen for anti-inflammatory activity. IICT, Hyderabad has established new NSAID enfenamic acid and marketed it (Tromaril®, Unichem Laboratories, Mumbai). The work on curcumin (*Curcuma longa*) and boswellic acid

New Drugs Developed in India

Year	Drug	Use	Organization
1956	Methaqualone	Hypnotic	CSIR
1958	Peruvoside	Cardiotonic	CSIR
1961	Hamycin	Anti-Fungal	HAL
1972	Cebtimizone	Anti-Thyroid	CSIR
1976	Sintamil	Anti-Depressant	CIBA-GEIGY
1980	Tromaril	Anti-Inflammatory	CSIR
1986	Cibemid	Anti-Protozoal	CIBA-GEIGY
1986	Gugulipid	Hypolipidaemic	CSIR
1987	Centbucridine	Anaesthetic	CSIR
1987	Centbutindole	Neuroleptic	CSIR
1991	Centchroman	Contraceptive	CSIR
1994	Chandonium Iodide	Neuromuscular Blocking agent	CSIR
1995	Centpropazine	Anti-Depressant	CSIR
1997	Thrombinase	Clot dissolving	JIPMER
1998	Artemisenin	Anti-malarial	CSIR
2000	Aablaquine	Anti-malarial	CSIR

India's 'Numero Uno' Exporter of Drugs:

Ranbaxy Laboratories Ltd. New Delhi hit the headlines in 1970's by breaking the price stranglehold of a MNC on diazepam. Calmpose produced by it soon became a 'mega brand' (annual sale over Rs. 100 million).

Ranbaxy now produces about 50 bulk drugs with indigenously developed technologies. It markets them in India and 55 other countries with exports accounting for 45% of its total sales. It has factories in China, Netherlands, Ireland and USA.

Themis India is marketing Arteether (E.Mal) to over 40 countries. Artemether produced by Ipca Laboratories is exported to Sudan, Kenya and Hongkong.

(*Boswellia serrata*) has been mentioned earlier.

Pulmonary Pharmacology: The nature of 5-HT, histamine and acetylcholine receptors in various segments of bronchial tree in mastomys, rhesus and langur monkey has been analysed. ICMR is clinically evaluating several traditional remedies in bronchial asthma. Detailed studies have been done on anti-allergic activities of *Albizia lebbeck, Picrorhiza kurroa, Solanum xanthocarpum* and *Tylophora indica*.

Pharmaceutical Industry

The Indian pharmaceutical industry, with a history of over 100 years, has progressed substantially during the last 50 years. The Industrial Policy Resolution of 1948 led to the setting up of Hindustan Antibiotics, Pimpri near Pune, Maharashtra in 1950s and IDPL plants in 1960s in the Public Sector and resulted in self-sufficiency in several major drugs. Another important milestone was the Patents and Designs Act of 1970, which allowed only process patents for pharmaceutical products. Both greatly accelerated the development of process technology and laid the foundation of the 'Pharma Revolution'.

Process Technology: The drug houses neither had the funds nor the resource base for indigenous technology after Independence. Hence technology was imported and modified if necessary. In some cases it was improved and even re-exported. Help was taken from national laboratories like NCL, Pune; IICT, Hyderabad and CDRI, Lucknow. In the next phase, in- house technology was developed and vertically integrated for important drugs like steroids, vitamins (A, B6), trimethoprim, diazepam etc. For some (e.g. Calmpose®) a strong brand equity was also built up. Gradually India became a leading global producer of drugs like ephedrine, d-propoxyphene, and clofazimine etc using indigenous technology. Several drug houses built their own R&D facilities and developed processes for new drugs like ranitidine, leading to dramatic reduction in national and even international prices. A recent example is CIPLA's success in making available the anti-HIV drugs at about one seventh of the international price. About 100 major drugs are produced using totally indigenous cost-effective technologies. Several processes for generic drugs have received international patents and bulk drugs, made in GMP norm factories, are exported to USA, Europe etc. There is increasing collaboration between the industry, academia and research institutions for vertically integrated and globally competitive technologies, especially for vital, expensive or patent-expiring drugs.

New Drug Discovery Research (NDDR): NDDR not only requires multidiscplinary facilities and expertise but also a large financial outlay. Few Indian companies were in a position to initiate such projects in early years. They collaborated with National Laboratories and the first drug was CDRI's anti-thyroid mipinazole (Centimizone®, Unichem) followed by IICT, Hyderabad's NSAID enfenamic acid (Tromaril®, Unichem). The multinational companies and Indian Companies such as CIBA and Hoechst, Sarabhai Chemicals and Public sector HAL and IDPL first set up

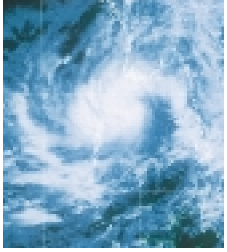
facilities for NDDR. Unfortunately these ultimately closed down. The two products marketed were Hamycin® (HAL) and Sintamil® (CIBA). The next 10 drugs were developed by CDRI and licenced to industry. During the last decade a few drug houses have developed NDDR facilities. The most active are Ranbaxy (Ranbaxy 2258, Parvosin)and Dr. Reddy's Laboratory. Several of their molecules are under clinical evaluation for benign prostatic hypertrophy (Ranbaxy 2258, Parvosin®), diabetes (DRF 2725, 2593) and cancer (DRF 1042). Cox-2 inhibitor, anti-asthmatic etc. are under advance pre-clinical assessment. Drug companies are also collaborating with academia and research institutions for synthetic or plant based drugs or for new dosage forms like liposomized amphotericin mentioned earlier.

Economic Indicators

The pharmaceutical industry is self-reliant, vibrant and export oriented. Until 1960s the Indian drug prices were among the highest in the world and the country was a net importer. Today India is a net exporter and the Indian drug prices are among the lowest. In some instances the difference is 30- (Flucanozol, Kenya) to 60- fold (Zantac, South Africa; Voltaren, Argentina). Several units can sustain NDDR. The data in Table give an indication of the tremendous growth of the pharmaceutical industry since 1950. The period has been divided in 2 or 3 segments. But growth in the last decades has been remarkable. The annual production of bulk drugs rose from Rs. 7,300 million to Rs. 31,480 million and of formulations from Rs 3,840 million to Rs. 13,920 million between 1990 and 1999.

The Indian companies have outperformed the multinationals (MNCs) operating in India from given below the percentage growth in select performance indicators such as total sales, gross profits and profit after tax in 2000-2001 over the preceding year.

The pharmaceutical Industry of India has developed the ability to respond quickly to new demands, has achieved a remarkably high degree of vertical integration, built units with world class GMP compliant manufacturing facilities, and has emerged as a globally competitive cost efficient producer of quality drugs and pharmaceuticals.



CHAPTER XIX

BIOPHYSICS AND STRUCTURAL BIOLOGY

Research in biophysics had an early start in India in the late nineteenth century when the renowned physicist J.C. Bose began his pioneering work on the behaviour of cells under external stimulii. He also invented many delicate and sensitive instruments. The best known among them is the crescograph for recording plant growth.

Among the modern biophysicists of India, and indeed of the world, the name of G.N. Ramachandran stands out as the most outstanding scientist to have worked in Independent India. The structure of the fibrous protein collagen, proposed by him and Gopinath Kartha in the first half of the 1950s, has been an intellectual achievement of the highest order and has stood the test of time. The Ramachandran plot, devised in the early 1960s, still remains the simplest and the most commonly used descriptor and versatile tool for the validation of protein structures. His contributions to the foundations of crystallography have been immense and in the area of image reconstruction he made major contributions. He initiated and pursued conformational studies on all major biopolymers and laid the foundations of the currently thriving field of molecular modelling. He founded two renowned schools of biophysics and structural biology, one at Chennai and the other at Bangalore. Although Ramachandran left the field nearly a quarter of a century ago and died recently, his work continues to exert great influence on structural studies of biomolecules.

N.N. Dasgupta of Kolkata has been another pioneer in the field of biophysics in India. He constructed an electron microscope in the middle of the last century and, among other things, visualised the cholera phage DNA. Another leading scientist associated with the early development of biophysics in the country has been A.R. Gopal-Iyengar who, working at Mumbai, made outstanding contributions in the basic and the applied aspects of radiobiology, radiation biophysics, cellular biophysics and related areas. Both of them left behind flourishing schools of biophysics. The others involved in pioneering efforts in the 1950s and the 1960s include D.M. Bose, N.N. Saha, S.N. Chatterjee, R.K. Poddar (all from Kolkata), S.R. Bawa (Chandigarh), R.K. Mishra (Delhi) and K.S. Korgaonkar (Mumbai).

In addition to the students and colleagues of the early pioneers of biophysics in the country, a substantial section of the present leaders of biophysics and structural biology in India entered the field through doctoral or postdoctoral studies at leading schools in different parts of the world. Thus, the biophysics and structural biology community in India today is a vibrant mosaic made up of different strands of traditions and expertise.

CURRENT STATUS

Today, close to a hundred research groups distributed in different institutions in the country are engaged in research in the field of biophysics. Among them, they cover almost all aspects of bio-

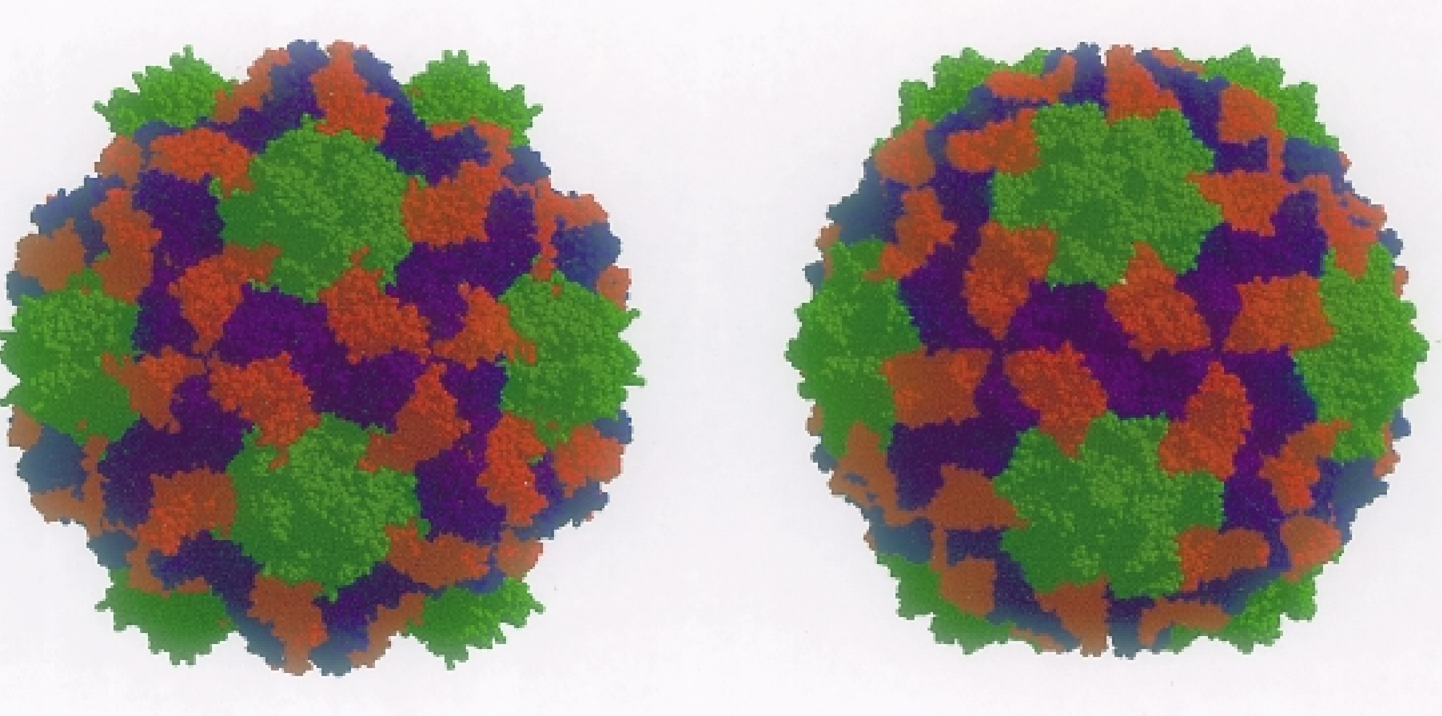


Photo: M.R.N. Murthy

Space-filling model of sesbania mosaic virus (left) and physalis mottle virus (right). Sesbania mosaic virus has a smoother surface when compared to physalis mottle virus which displays prominent protrusions at the 5-fold symmetry axis.

physics, especially at the molecular level. The range of activities is so extensive that it is impossible to cover all of them in a brief summary and the fact that the boundaries of biophysics are too porous to be defined makes the task all the more difficult. The effort here, therefore, is to give a gist of current biophysics research in India without making any attempt to be comprehensive. The strongest component of biophysics research in the country, and perhaps in the world, is concerned with molecular biophysics which, in modern parlance, is called structural biology. The emphasis here would thus be naturally on structural biology.

Proteins and Peptides: G.N. Ramachandran and his colleagues were pioneers in structural studies on proteins at the international level. Much of their work has been computational or theoretical. The most important approach to studies on protein structure involves biological macromolecular crystallography. Work in this area was initiated early in the 1980s at the Indian Institute of Science (IISc) Bangalore, and the Bhabha Atomic Research Centre, Bombay. The endeavour gathered momentum with the implementation of the Thrust Area Programme of the Department of Science & Technology (DST) in 1983, when Bangalore was identified as a national nucleus for the development of this research area in the country. Since then, particularly in the 1990s, a number of research groups in macromolecular crystallography came into being in different parts of India with support from DST, the Department of Biotechnology (DBT) and the Council for Scientific and Industrial Research (CSIR). There are currently a dozen such groups located at nine institutions. The Indian effort in this area has been well coordinated and has a significant international presence.

The macromolecular crystallographic studies in India range across a wide spectrum. Crystallographic studies on lectins, in conjunction with biochemical and physico-chemical investigations, carried out in India has had considerable international impact. The structure analysis of two plant viruses has been among the landmarks in the development of structural biology in India while studies of lactoferrins from different sources constitute an important component, as do those on phospholipases

GOPALASAMUDRAM NARAYANA RAMACHANDRAN
1922-2001

Considered one of the founders of molecular biophysics, G. N. Ramachandran was also a crystallographer of international repute. He was fascinated by the arrangement of molecules in proteins and so decided to take up research in this field. His work on the collagen molecule brought him worldwide reknown in the scientific community.

Ramachandran was born on October 8,1922 in Ernakulam district of Kerala. He studied for a Master's degree in electrical engineering in 1940. He received his D.Sc. from the University of Madras in 1948 and completed his Ph.D. from the University of Cambridge in 1949. In 1951, he went back to Cambridge, England, to work with Sir William Lawrence Bragg, the 1915 Nobel Laureate in physics, and W.A. Wooster, and returned home with another Ph.D.

Ramachandran is credited with the establishment of the Department of Physics at the University of Madras in 1952. He began work on modeling collagen from fibre diffraction in 1952-53, when J.D. Bernal, who did pioneering work in X-ray crystallography, visited him in Madras and suggested that the structure of collagen was one of the greatest unsolved problems. In 1954, Ramachandran arrived at the triple helix model which had two hydrogen bonds per unit. Dr Francis Crick, co-discoverer of the structure of the DNA molecule, had independently deduced one hydrogen bond per collagen unit. More recent single crystal work has shown the result to be 1.5 hydrogen bonds per unit, a compromise between these two proposals.

In 1968, he was made the Jawaharlal Nehru Fellow at the University of Madras. In 1971, the Indian Institute of Science in Bangalore invited Ramachandran to set up the Department of Molecular Biophysics. Soon he managed to raise the Department to an international status where research was carried out on several giant molecules of biological importance, for example, nucleic acids and polysaccharides.

In the 1970s, he turned to problems of mathematical logic and proposed a new method for structural analysis in 1990. Ramachandran's work with A. V. Lakshminarayanan has been acclaimed as the starting point of the CAT scan technique in radiography.

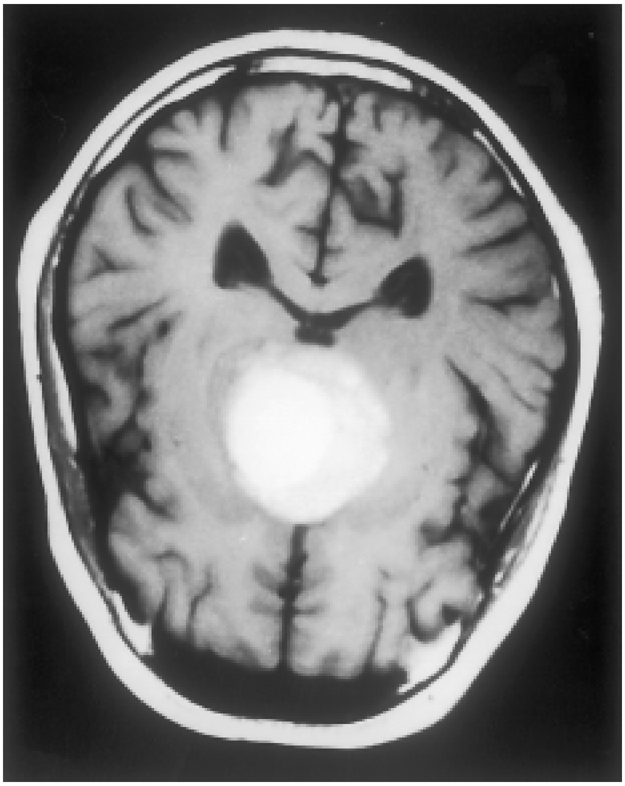
Ramachandran who was honoured with the prestigious Ewald Prize in 1999 for his outstanding contribution in the field of crystallography, died in Chennai on April 7, 2001 after a long illness.

and xylanases. Carbonic anhydrase and its complexes have been extensively studied in the country and work on ribosome-inactivating protein, and proteolytic enzymes and their inhibitors deserve mention. Substantial contributions have emanated from India in structural approaches to molecular mimicry. Crystallographic and related studies on immunological systems are now gathering momentum. Yet another crystallographic contribution from India pertains to the hydration, plasticity and action of proteins. An exciting recent development in the area is the concerted effort on proteins from *Mycobacterium tuberculosis*.

Nuclear Magnetic Resonance (NMR) is widely used in chemistry and biology, and structure determination of proteins using NMR is currently gathering momentum in India. The structures of a couple of proteins, a calcium-binding protein and a novel neurotoxin, have already been determined at the Tata Institute of Fundamental Research, Mumbai, which houses the largest national NMR facility in the country. Serious efforts in the area are now underway in a few more centres in the country. In addition to working on individual or

groups of molecules, the Mumbai centre and the NMR centre at the IISc, Bangalore, which houses a widely used national facility, have made important contributions to the methodology of 2D and 3D NMR spectroscopy.

Computational approaches to protein structure continues to be an important component of biophysical research in India. The work in the area encompasses homology modelling, protein-ligand



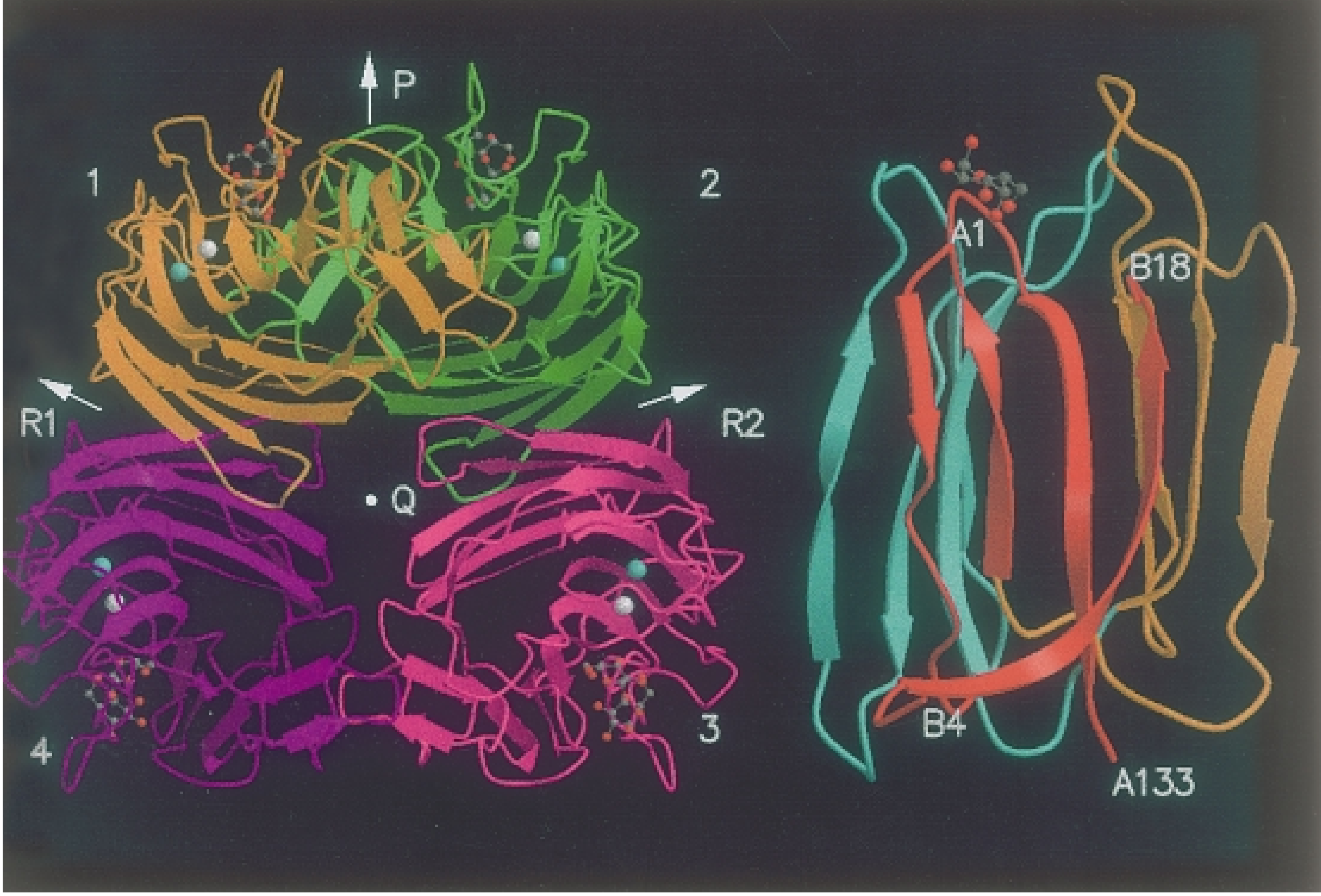
Transaxial T1-weighted proton MR image of a patient showing clearly the tumor near the 3rd ventricle region of the brain.

interactions, study of secondary and other special structural features, and data analysis.

Biophysical chemistry is central to modern biology. There was a phase in India when studies in this area appeared to be on the decline but in recent years, work in the area has gathered great momentum, particularly in relation to the folding, stability and design of proteins. High-quality work of international standard on protein folding is currently being carried out in several laboratories in India. Some of them primarily address general questions, while others tend to concentrate on particular systems. The systems encompass proteins from widely different families. Protein stability, to a substantial degree, is related to protein folding. This is reflected in the work carried out in many laboratories. The role of water, metal ions, ligands and additives in protein stability also form a topic of detailed investigations.

Molecular design provides a link between proteins and peptides. Design and synthesis of oligopeptides with desired conformations, particularly using conformationally restrictive amino acids, have been an area of considerable strength in the country. Such peptides are then used as modular units for the subsequent synthesis of proteins. Imaginative use of crystallography and NMR has played an important part in this effort. Interactions involving amino acids and peptides and their relevance to present-day biological systems, as well as to processes involved in the origin of life, have been investigated in considerable detail. Synthetic, spectroscopic, crystallographic and theoretical studies have also been carried out on several peptide systems.

Nucleic Acids: Theoretical conformational studies on nucleic acids were initiated by G.N. Ramachandran and were carried forward by V. Sasisekharan and his colleagues. In structural studies, using crystallography, on DNA, M.A. Viswamitra has been another pioneer. Computational and crystallographic studies, particularly on the sequence-dependent structure of DNA, continue to be pursued seriously in several laboratories. Extensive work on the structure determination of oligonucleotides using NMR has emerged, particularly from the TIFR, Mumbai. Work at this centre has produced a wealth of information on unusual DNA structures. In the process, important contributions to NMR methodology specifically applicable to DNA, have



The unusual quarternary structure of peanut lectin (left) and a subunit of jacaline which exhibits a novel lectin fold (right).

also been made. DNA-ligand interactions are pursued vigorously, mainly using spectroscopic and physico-chemical techniques. The recently recognized importance of trinucleotide and other repeats has added a new dimension to the structural studies on DNA.

Membranes: The biological membrane, the ubiquitous multimolecular system found in living organisms, and related models, have received considerable attention from biophysicists. India has been no exception in this regard. The organization, heterogeniety, dynamics and asymmetry of membranes have been studied extensively, using spectroscopic and physico-chemical approaches. The Indian contribution towards the synthetic, spectroscopic, crystallographic and computational studies on ionophores has been very substantial. The same is true about the interaction of drugs and other active molecules with the membrane. Significant contributions have also been recently made from India to ion channels with implications, among other things, for neurobiology.

Carbohydrates: Carbohydrates have emerged as very interesting molecules during the past couple of decades. A substantial part of biological recognition is mediated by sugars. Work on proteins that bind sugars such as lectins, has already been referred to. Pioneering efforts of V.S.R. Rao and his colleagues on polysaccharide conformation have been noteworthy. Yet, work on carbohydrates and glycoconjugates in the country is much less extensive than it ought to be, although there are some groups working in the area.

Computational Biology and Bioinformatics: Indians have been in the forefront of international efforts in computational biology during the emergent phase of

the field and work in the field continues to be pursued vigorously in the country. Some components of it have been referred to above. There are groups of scientists, distributed over the country in different centres, who are exclusively concerned with computational biology. Thanks to a major initiative of DBT, India has been among the first countries to embark on a concerted effort in the allied field of bioinformatics. A network of bioinformatics centres have been established covering all regions of the country for the dissemination and analysis of different data bases. This network has played an invaluable role in taking bioinformatics to the biology community as a whole. The emphasis of the bioinformatics programme is shifting from dissemination to generation of data bases and software.

Whole Systems: Structural biology has to some extent dominated biophysics in recent years. However, biophysical studies at higher levels of organization continue to be pursued as for instance in NMR investigations of whole cells and metabolic processes and, importantly, in MRI studies on neurological processes. Optical studies of different types on biological systems are being carried out in a few centres. Radiation biophysics is another area in which significant activity exists while work in medical biophysics and on biomaterials is being pursued at a few centres.

Unlike in the case of computational biophysics, mathematical biology has had only limited following in the country. However, a trend towards wider acceptance of the area is now discernible. Theoreticians, particularly theoretical physicists, are currently showing increased interest in the mathematical modeling of biological systems.

Trends and Prospects

Even in normal circumstances, predictions rarely come true in science. This is even more so at present when rapid and revolutionary changes are taking place in almost all branches of biology. All that one can reasonably do is to indicate some trends.

For long, much of the biophysics research in India, impressive though it was, took place independently of the bulk of the biological research activities in the country. Work in crystallography and computational biology exemplifies the situation. Most of the workers in these areas used to be physicists and had little professional contact with biologists. The situation is rapidly changing. A number of multi-disciplinary collaborations have developed. Structural biologists are now very much part of the biology community and biology laboratories are rapidly becoming natural habitats of crystallographers and computational biologists. This trend is likely to accelerate in the years to come.

The development of biological macromolecular crystallography in India provides a good example of a concerted effort towards building up momentum in an important scientific programme in the country. The area of biological macromolecular crystallography is well past the stage of capacity building and many important problems have already been successfully addressed at a globally competitive level. Work using the crystallographic approach is poised to take further major strides, with the active involvement of biologists working in other areas. A further impetus in this direction is expected to be provided by the recently evolved multi-institutional programme on the structural genomics of microbial pathogens. As indicated earlier, macromolecular structure determination using NMR is well underway in one major centre in the country and major results in the area are expected in the near future, from at least two more centres. However, in experimental approaches to macromolecular structure determination, a major gap area in the country is cryo-electron microscopy. Efforts to fill this gap will be very worthwhile. The major thrust of biological structural studies in India has been concerned with proteins that act on carbohydrates, plant viruses, lactotransferrins, proteolytic enzymes and their inhibitors, protein hydration, molecular mimicry and structural variability of DNA. These lines of investigation are expected to be further

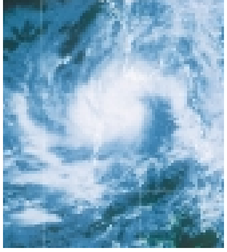
strengthened. Work on immunologically relevant problems, which has already been initiated, is likely to gather additional momentum in the near future. A major new thrust is expected in structural studies on proteins from microbial pathogens.

A major theme of structural studies on peptides has been concerned with protein folding and design. Physico-chemical, thermodynamic, structural and theoretical studies in this area will continue to be an important element of structural biology in the country while biophysical and theoretical approaches should continue to play a major role in multifarious studies on membranes.

The primary emphasis of the bioinformatics programme in India so far has been on the dissemination of information. That phase is now over. Efforts are already underway for the creation of novel data bases and the development of web-based software. These efforts, which are now gathering momentum, are likely to occupy centre stage of bioinformatics in the country in the future. The initiatives in genome analysis have added a new dimension to these efforts. In general, with the departure of giants of yesteryears, the visibility of computational biology as a distinct approach, diminished somewhat during the closing decades of the twentieth century. This trend is now being reversed as a new generation of practitioners in the area have appeared and seem to be set to make a significant impact on biology.

Work on whole systems, particularly using imaging techniques, is expected to be further carried forward in the years to come. There is currently a clearly discernible and welcome trend towards harmonizing studies at the molecular and the organismal levels. This trend needs to be, and is likely to be, strengthened in the future.

Recent years have witnessed the rapid evolution of a host of new approaches and novel techniques to deal with biology at different levels of organization. Most of them involve a great deal of what is conventionally described as biophysics. However, the borders between different sub-disciplines of biology are becoming increasingly blurred. Studies at different levels of biological organization have also begun to get progressively integrated. In this rapidly changing scenario, it is difficult to foretell how the new approaches and techniques will develop in the country. However, modern biological research in India is sufficiently mature and resilient to be able to cope with the rapid developments and contribute to them.



CHAPTER XX

Biochemistry

Biochemistry was recognized as a separate discipline in the beginning of the 20th century with the establishment of the first Department at the University of Liverpool. Many scientists would not know that the second Department exclusively devoted to biochemistry was set up in the world at the Indian Institute of Science (IISc) in Bangalore in 1921. Biochemistry is a mother discipline for all biological sciences, as it deals with molecular reactions of biological phenomena in all living cells. Biochemistry has grown and flourished in India with advanced level teaching in nearly 50 universities and research in over 75 departments including those of national laboratories. The growth of this discipline in India has kept pace with the rest of the world by the generation of new ideas and application of advanced technologies. This article highlights important achievements in the past five decades. The account is divided into two periods: 1950-80 and 1980-2000, recognizing that novel molecular biological tools and technologies became available in the early 1980s which were quickly adopted in the Indian laboratories for seeking answers to a wide spectrum of fundamental biological questions.

BIOCHEMISTRY HAS GROWN AND FLOURISHED IN INDIA WITH ADVANCED LEVEL TEACHING IN NEARLY 50 UNIVERSITIES AND RESEARCH IN OVER 75 DEPARTMENTS INCLUDING THOSE OF NATIONAL LABORATORIES.

No comprehensive account is attempted. Some of the important research findings made during the first three decades are summarized under a few headings:

Sanitation and Health

Sanitation biochemistry was an important subject pursued at IISc in the early years particularly with respect to natural purification of sewage in Bangalore by using activated sludge process and examining the role of protozoa and *Vorticella* sp. These activities led to the setting up of the National Environmental Engineering Research Institute at Nagpur. The biochemistry of pathogenic bacteria was initiated at the Central Drug Research Institute (CDRI) Lucknow, Vallabhbhai Patel Chest Institute (VPCI) Delhi, and IISc, which dealt with delineating the pathways of degradation and biosynthesis of amino acids, utilization of sugars and mechanism of action of antitubercular drugs. Biochemistry of Kala Azar was taken up at the All India Institute of Experimental Medicine (AIIEM), Kolkata, now called Indian Institute of Chemical Biology (IICB) Kolkata, which was very relevant in the context of the re-emergence of this disease in eastern UP and Bihar. The biochemistry of filarial worms and helminth par-

asites was investigated at Lucknow and Chandigarh. Respiratory diseases were studied at VPCI. Drug metabolism and pesticide metabolism were other areas of research carried out during this period at Bangalore and Lucknow respectively. Biochemical adaptation to high altitude and low temperature environment prevalent in the Himalayan peaks was studied at Bangalore and Delhi.

Food Research

The early work at IISc on foods and food processing centered around the development of nutritive food formulations and fortification with vitamins. These early studies paved the way for the establishment of the Central Food Technological Research Institute (CFTRI), in Mysore, which has become one of the premier institutions of CSIR today. Food research was also carried out in the Food Technology Department of the Bombay University and the Hindustan Lever Research Laboratories. The pioneering work at BARC, Mumbai, has resulted in the development of extremely useful methodologies for preserving canned foods and spices using radiation.

Enzymology

Enzymes are the central players in biochemistry and have attracted the attention of several researchers over the last five decades. Enzymology which had its beginning at IISc, Bangalore, has become even more important in the postgenomic era since we need to understand the functions of thousands of genes discovered in silico based on the sequence information of several organisms. In the early 1950's emphasis was on the study of enzymes involved in the metabolism of amino acids, lipids, vitamins, plant hormones and nucleic acids. The most important contribution during this period was the study of reactions in trans-glycosylation. With the availability of sophisticated spectroscopic and kinetic techniques, subsequent work in the 1960s was centered round the regulation of enzyme activity by small molecules. Metabolic pathways for the bioutilization of aromatic compounds and characterization of the enzymes involved as well as their mechanism of action attracted serious consideration during this period. The structure-activity relationship of ribonuclease and its intermediates in the *pH* and temperature-induced denaturation process was a major contribution from IISc. Amino acid and nucleic acid metabolism in *Mycobacterium tuberculosis* and *Mycobaterium smegmatis* were studied in great detail during this period at IISc.

An active and vibrant school of enzymology was developed during this period at the University of Calcutta. The group studied the biosynthesis of ascorbic acid and this research has been continued even during 1980-2000. The enzymes regulating the biosynthesis of inositol phosphates, RNA, DNA and protein biosynthesis were studied in Kolkata.

Indian Institute of Science, Bangalore.



Photo: V. Krishnan

Enzymes of carbohydrate metabolism and thyroxin were investigated at IICB. Epimerases and their regulation were studied at the Jadavpur University. Enzymology research also flourished during this period at the Madras University where work was carried out on phosphoprotein phosphatase, niacine-tryptophan interrelationship and trace element metabolism. Pioneering work on the structure of collagen and theoretical work on the conformation of proteins were carried out in Chennai during 1960's.

Hexokinase, enzymes of the citric acid cycle and phosphatases were extensively probed at the University of Poona. Enzymology was also actively pursued in Mumbai at TIFR, BARC and Cancer Research Institute (CRI). At TIFR, major emphasis was laid on alkaline phosphatase and genetics of pyruvate kinase and hexokinase. Lactate dehydrogenase, hexokinase and enzymes of folate metabolism were studied at BARC. Enzymes from snake venom and dihydrofolate reductase were studied at CRI. Enzymes of carbohydrate metabolism were also studied Nagpur and Hyderabad. At Aligarh and Ahmednagar, the emphasis had been on the physico-chemical and evolutionary aspects of proteins like haemoglobin and albumin. Research work at Ahmednagar resulted in deriving a phylogenetic tree based on the sequence of amino acids in proteins.

Vitamins and Nutrition

The Department of Biochemistry, Calcutta University, gained considerable importance for its work on vitamin C particularly on the biosynthesis of ascorbic acid and the role of viatmin C in diverse biological processes. Significant contributions have been made on vitamin A at the Department of Biochemistry, IISc. The National Institute of Nutrition, Hyderabad, has done excellent work in the field of nutrition research, particularly on vitamin A deficiency, vitamins B and nutritional disorders such as pellagra, marasmus, and kwashiorkor.

Lipids and Biomembranes

The Bangalore group has made significant contributions to our understanding of the absorption of phospholipids, glycerides and cholesterol in addition to the biosynthesis of phospholipids in animal tissues, glycolipids in photosynthetic tissues, herbicide effects on plant lipid metabolism and biogenesis of cholesterol. A major finding has been the identification of ubiquinone in non-mitochondrial membranes which is now being shown to be important as an antioxidant in conjunction with vitamin E. The effect of vitamin A deficiency and hyper-vitaminosis on lipid metabolism in *Mycobacterium tuberculosis* were studied at VPCI, Delhi. Biogenesis of mitochondria was actively studied at Bangalore and Madurai. Physical approaches have also been used to study the membrane functions at Bangalore. Liposomes and their importance in drug delivery were extensively studied at IICB, Kolkata.

Endocrinology

Endocrinology was an active area of research during the period 1960-80 which included a) mechanism of action of gonadotropins and steroid hormones, b) biosynthesis of iodotyrosine and thyroxine in extrathyroidal tissues, c) regulation of biosynthesis of gonadotropins, d) biochemical and immunological approaches to contraception, d) mechanism of action of centchroman, e) comparative endocrinology of birds, fishes and other lower vertebrates, f) gonadotropin inhibitors g) glucagon and insulin secretion in diabetes, h) adrenal steroids and gastric ulcer, i) use of plant products as contraceptives and j) antisteroid drugs as inhibitors of sperm maturation. Several aspects of male and female reproduction were studied at IISc, All India Institute of Medical Sciences (AIIMS), New Delhi, and Institute for Research in Reproduction (IRR), Mumbai. Reproduction-specific vitamin-carrier proteins have been isolated and characterized. One of the major efforts during this period was to explore the feasibility of immunological approaches to contraception.

Plant Biochemistry

There was sustained research activity in plant biochemistry in several places during this period, which included the study of pathways of aromatic amino acid metabolism, plant hormones, enzymes from plant sources, mechanism of drought tolerance, mechanism of host-parasite interactions, photosynthetic processes in C3 and C4 plants, role of nitrate and nitrite reductases in nitrogen fixation.

Neurochemistry

Christian Medical College (CMC), Vellore, was the first school of neurochemistry and glycobiology in India. The scientists there demonstrated the cause of an inborn error of metabolism, metachromatic leucodystrophy by establishing the deficiency of the enzyme arylsulphatase in the brain tissue.

The M.S. University of Baroda, has developed a research programme in the area of neurochemistry especially related to nutrition and brain function. The group in the University of Calcutta has done a lot of work on mode of action of psycho-pharmacology of drugs.

The National Institute of Mental Health and Neurosciences (NIMHANS), Bangalore, has a strong research group working on motorneuron disease, neuroepidemiology and clinical neurophysiology. The Institute has also been engaged in the basic and applied areas of mental health and psychiatric disease.

Neurochemical research was conducted at AIIMS, New Delhi; CMC Hopsital, Vellore; CRI, Mumbai; Post Graduate Institute of Medical Research, Chandigarh; IICB, Kolkata; National Institute of Nutrition, Hyderabad; and IISc, Bangalore. The studies included sensory perception in developing brain, neurotoxicity of snake venom, effects of malnutrition in brain development, myelogenesis and synaptogenesis, nucleic acid metabolism and psychopharmacology.

Molecular Biology

In the beginning, the discipline of molecular bio logy concerned with only the aspects of nucleic acid metabolism, protein synthesis and gene regulation. However, subsequent developments in recombinant DNA technologies gave a new turn to our understanding of the various biochemical aspects of life processes. With the recent advent of biotechnology as a very important component of Life Sciences, molecular biology is now understood as only a tool or means to unravel cellular processes.

In the early years before 1980s, the major areas of research were 1) bacteriophage genetics and control of gene expression in phage-infected bacteria, 2) bacterial genetics: chromosome mapping, study of genes specifying DNA recombination and replication, 3) regulation of DNA repair function, 4) ribosome structure and function, 5) molecular basis of host-virus interaction, 6) structural studies on DNA, tRNA, 5S RNA and protein-nucleic acid interaction, 7) chromatin structure and function, 8) molecular mechanisms underlying differentiation in plants and lower eukaryotes and sporulation in bacteria, and 9) regulation of X-chromosome inactivation. The Molecular Biology Unit at Banaras Hindu University (BHU), Varanasi, has contributed significantly to the molecular basis of host-virus interaction and structure and function of the *E.coli* ribosome. This group has shown that the structure of ribosomal RNA plays a significant role in protein synthesis. Salient contributions were made at IISc, Bangalore, on alternate structures in DNA, modified bases in tRNA, immunological aspects of nucleotides, regulation of heme biosynthesis, chromatin structure and function, animal viruses, hormonal regulation of gene expression and so on.

The School of Biolgical Sciences at Madurai, has been actively engaged in teaching and research in Molecular Biology over the years. The important research interests of this school had been 1) gene regulation during bacterial sporulation and development of *Artemia salina*, 2) transcription mutatns of *E.coli*, and 3) organelle gene expression

plants. Significant contributions were made on transcriptional regulation of gene expression using coconut endosperm nuclei as the experimental system at Bose Institute, Calcutta. DNA repair using the phage systems were actively pursued at the Biophysics Department, Calcutta University. The Molecular Biology Unit at TIFR Bombay, has been a major centre of Molecular Biology research since its inception in 1962. The areas of research included genetic transfer mechanisms in *E.coli*, theoretical and experimental work on ribosome biogenesis and protein structure, neurobiology, molecular aspects of olfaction in *Drosophila*, yeast genetics, pattern formation and molecular biology of tumor viruses. The Centre for Cellular and Molecular Biology (CCMB) at Hyderabad was established during this period by CSIR and the initial work was on molecular mechanism of action of seminalplasmin and reverse transcriptases. The School of Life Sciences at JNU also started during this period and the initial efforts were on translational control mechanisms in eukaryotes. The group at JNU has worked extensively on protozoa parasite, *Entamoeba histolytica*, particularly on genome structure, and also on the molecular genetics of nitrogen fixation and have also shown the presence of multiple chromosomes in *Azotobacter vinelandii*. More recently another group at JNU has reported a novel gene encoding hyaluronic acid binding protein located on human chromosome 17 related to signal transduction pathway.

> DEVELOPMENTS OF THE MOLECULAR BIOLOGICAL TOOLS INCLUDING THE RECOMBINANT DNA TECHNOLOGIES HAVE GIVEN A NEW DIRECTION TO OUR APPROACH TO UNDERSTAND LIFE PROCESSES.

BIOCHEMISTRY SINCE 1980

As mentioned above, developments of the molecular biological tools including the recombinant DNA technologies have given a new direction to our approach to understand life processes. Also the borderline between the different disciplines is no longer water tight. We can broadly classify the recent progress into the following areas namely, Biochemsitry and Biotechnology, Cell biology, Immunology and Structural Biology. The contributions in these areas at various centres has been summarized. It is to be mentioned that the establishment of the Department of Biotechnology by the Government of India as a separate Scientific Department has given a great stimulus to research and training in this field in India over the last two decades. The Department of Biotechnology in addition to supporting the development of infrastructure at the major research centres, has also contributed to the development of humanpower by opening M.Sc. courses in Biotechnology at several universities. It has also started postdoctoral training at a few select institutions.

Protein structure and molecular enzymology continues to be one of the major areas being pursued at IISc, using site-directed mutagenesis approach. The enzymes studied include serine hydroxy methyl transferase, restriction-modification enzymes, proteins involved in genetic recombination, histones and other basic proteins, enzymes involved in DNA repair, enzymes involved in fatty acid biosynthesis and others. There has been sustained research on molecular aspects of genetic recombination in *E.coli*, yeast and mammals. Over the last decade molecular aspects of infectious diseases particularly tuberculosis, malaria and Japanese encephalitis virus have received serious attention. The molecular virology of animal and human viruses is being extensively studied with the objective of developing vaccines in the near future. Gene regulation in prokaryotic and eukaryotic systems using model

genes has been extensively studied which includes cytochrome P450 in rat liver, tRNA genes in silk worm, *mom* gene from bacteriophage, *TGF beta*, cryptic genes of *E.coli*. Some of these studies have led to recent attempts to develop DNA vaccines. Research groups at IISc and JN Centre, Bangalore have recently obtained valuable information on certain important biosynthetic pathways in the malarial parasite. Protein folding is receiving critical attention as one of the important areas in which several important contributions have been made by researchers at IISc and National Centre for Biological Sciences (NCBS), Bangalore.

Structural Biology is a discipline in which India has made a mark in international science. This work began with the initial efforts of G.N.Ramachandran on conformations in polypeptides. More recently IISc has shown leadership in protein crystallography, a subject which is also being pursued in at least half a dozen relatively new research groups across the country. The results of research in the area of lectins from the Banglaore group are now well recognized particularly in relation to structure and specificity of interaction with sugars.

Over the past decade CCMB has become a premier research centre in biology. The Institute has developed a salt-inducible expression system in *E.coli* which has now been commercialized. This is a good example in which basic research has been transformed into a commercial product. CCMB has also developed a Bkm-derived probe for DNA fingerprinting, again an outcome of an important study in basic science. The development of this technology was the determining factor in the establishment of the Centre for DNA Fingerprinting and Diagnostics (CDFD) at Hyderabad by the Department of Biotechnology. Characterization of microbial biodiversity of the Antarctica and molecular basis of adaptation to low temperature, and the demonstration that crystallins may have a role in protecting the eye lens, and that one of the crystallins has a chaperone activity may function in modulating protein folding are other important findings of CCMB.

The National Institute of Immunology (NII), New Delhi, which was established by the Department of Biotechnology has been concentrating on various aspects of immune system, drug delivery, regulation of gene expression in the Bacculovirus system, development of vaccines, immunomodulators from plant sources and intracellular protein trafficking in pathogen-infected macrophages. NII has also contributed significantly in the area of reproductive biology and various approaches to contraception. Extensive work was carried out at NII and CRI on the feasibility of developing a vaccine against leprosy bacterium (*Mycobacterium leprae*).

The Department of Biochemsitry at Bose Institute, Kolkata, has been a major centre of research for several decades. Presently this Department is actively pursuing the biochemical and biophysical aspects of tubulin and antimitotic drug interactions. More recently structural biology of aminoacyl tRNA synthetases is being pursued using several biophysical techniques. Bacterial genetics continues to be one of the important areas of research. Yeast chromosomes and parasite biology are other major areas of research in this department. Theoretical aspects of protein structure and folding and experimental determination of protein structure by X-ray, and NMR are some of the new activities initiated recently.

The IICB at Kolkata is addressing several issues related to health and disease and more particularly parasitic diseases like leishamaniasis and cholera. Protein Engineering is one of the important areas that is being pursued here. The Institute is also known for its work on neurobiology and molecular endocrinology. More recently, work on human genetics has also been started particularly in the areas of gene flow across ethnic populations in India, animal models of inherited eye disorders and genomic diversity in Indian population. Significant contributions have been made on Indian population genetics from groups at the Indian Statistical

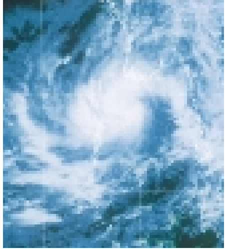
Institute (ISI), Kolkata.

The Institute of Microbial Technology (IMTECH), Chandigarh, is one of the relatively recent institutions in the country, which has concentrated on molecular biology of cholera, yeast genetics, and production of recombinant proteins of therapeutic interest. The Centre of Biochemical technology, New Delhi, has been known for studies on allergy caused by pollen and fungi and applied immunology. However more recently, it has diversified its interests into functional genomics and is engaged in active research using the information of human genome sequence on neurological disorders. The Centre is also engaged in using genome information to address the basis of respiratory disorders, tuberculosis and haemoglobinopathies. CDRI, Lucknow, has recently embarked on using the recent developments in the area of structural biology and genomic information in its efforts towards future drug research. TIFR, Bombay, continues to add to our knowledge of plant developmental biology, neurobiology and mechanisms of genetic recombination. The School of Life Sciences, University of Hyderabad and the Osmania University have been the major centres of masters degree training and research. The scientists of these institutions are investigating DNA repair and ageing, neurochemistry, plant biochemistry, biochemistry of eicosanoids such as prostaglandins and leukotrienes.

The Department of Zoology of the BHU is known for studies on the molecular aspects of ageing. The Department of Biochemistry at the University of Delhi South campus is one of the younger departments in the country but has already made significant work on molecular biology of tuberculosis, use of phage display for whole genome epitope mapping to identify immunodominant B-cell epitopes and development of a HIV detection kit. The researchers of this Department have received world wide attention for their work on intracellular protein trafficking and the development of a novel delivery system using Sendai virus model. Liposome-mediated drug delivery is also being actively pursued by them.

The International Centre for Genetic Engineering and Biotechnology, New Delhi, has developed strategies for developing vaccines against malaria, HIV and chloroplast transformation.

In conclusion, it may be stated that rapid strides and achievements in the areas of Biochemistry and other related disciplines have been made in India over the last decade. The number of publications in journals of international repute (high impact factor) have been steadily increasing. These have been possible because of the changing trends in leading laboratories in the world, development of novel techniques and tools and importantly generous support provided by the scientific departments, especially Department of Biotechnology, Government of India, in terms of humanpower development and upgradation of infrastructure in terms of high-technology equipment over the last decade.



CHAPTER XXI

AGRICULTURE

India's Independence was won in the backdrop of the great Bengal famine of 1942-43. No wonder, our first Prime Minister, Jawaharlal Nehru said early in 1948, *everything else can wait but not agriculture*. Thanks to the packages of technology, services and public policies introduced since the beginning of the first Five Year Plan in 1950, the country has transformed itself from a 'begging bowl' image to one which occupies the first or second position in terms of production and area in several major crops.

We also occupy the first position in milk production globally. India ranks second in fish culture and third in capture fisheries. We have been able to build substantial buffer stocks of food grains, in spite of increasing demand due to rising population. The per capita food grain availability has also increased by one and a half times.

India's share in the world production and area for major crops (1995 – 97)

Crops	India's Share (%)		India's Rank	
	Production	Area	Production	Area
Wheat	11.4	11.2	2	2
Rice	21.4	28.5	2	1
Coarse Grains	3.4	9.0	5	3
Potatoes	6.2	6.0	5	5
Pulses	26.0	36.6	1	1
Groundnut	28.6	35.2	1	1
Sugarcane	22.6	20.0	2	2
Tea	28.3	18.5	1	2
Tobacco	8.3	8.7	3	2
Jute	52.5	51.5	1	1
Cotton (Lint)	14.0	20.7	3	1

Source: FAO, 1997

Growth in food grain production and population during the last 50 years

	1950	1960	1970	1980	1990	2000
Food grain production(mt)	50.8	82.0	108.4	129.6	176.4	201.6
Food grain import(mt)	4.8	10.4	7.5	0.8	0.3	-
Buffer stock(mt)	-	2.0	-	15.5	20.8	40.0
Population (million)	361	439	548	683	846	1000

CROP IMPROVEMENT AND PRODUCTION

Wheat: Wheat has been cultivated for several thousand years in India. Wheat grains have been found in the Mohenjadaro excavations. These have been identified as belonging to *Triticum aestivum* sub-species *sphaerococcum*, characterized by spherical shape and dwarf plant stature. From the days of Mohenjadaro up to the dawn of India's Independence in 1947, the country developed the capacity to produce about 6 million tonnes of wheat. It was not sufficient to meet the demand, leading to large-scale importation of food grains.

In addition to strengthening of research and organization of a national extension service, several measures to stimulate food production including land reforms, irrigation, fertilizer production were initiated in the fifties. Production of wheat and rice

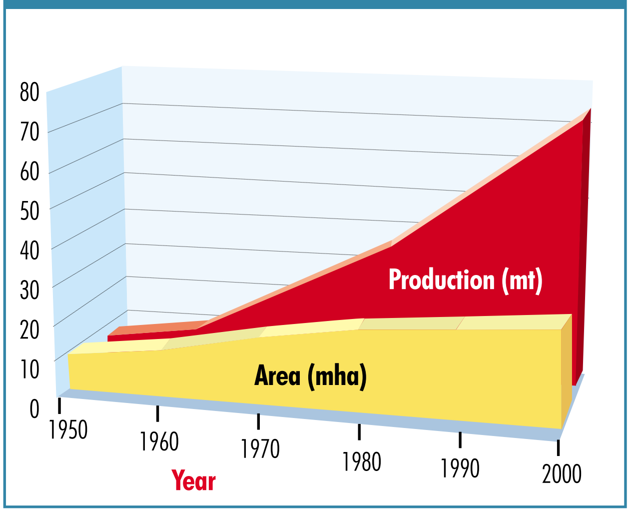


Green Revolution: ***Release of a postage stamp entitled 'Wheat Revolution' to commemorate quantum jump in wheat production by Indira Gandhi in July 1968 at the Indian Agricultural Research Institute, New Delhi.***

went up but productivity per unit area of land remained practically stagnant. Enhanced production came from an increase in both total cropped area and irrigated area. Wheat production went up to 12 million tonnes in 1964, which from the point of view of monsoon behaviour, was a good agricultural year. In order to enhance productivity in irrigated areas, the Government of India initiated the Intensive Agricultural District Programme (IADP) in 1961. The aim was to introduce good seeds and a package of agronomic practices which can help optimize the benefit from irrigation water. Unfortunately, the early IADP experience was not encouraging. It was found that the package of practices promoted had one important missing ingredient, namely varieties which can respond well to good irrigation and soil fertility management. It is this missing ingredient that was provided in 1966 through the High Yielding Varieties Programme (HYVP) in wheat, rice, maize, sorghum (jowar) and pearl millet (bajra). Wheat production rose to nearly 17 million tonnes in 1968. After several thousand years, the stagnation in yield was broken in wheat. Since similar productivity improvement was also visible in rice, the phenomenon has been described as "Green Revolution".

Wheat crop has exhibited a robust growth trend since the onset of the Green Revolution in 1968. In 2001 our farmers harvested nearly 74 million tonnes of wheat, while the wheat harvest at the time of our Independence was only 6 million tonnes. Much of the increase in wheat production has come from productivity improvement. Had this not occurred, we would have required nearly 74 million ha of area in contrast to the current actual area of about 26.7 million ha. It is rightly described as "land saving agriculture", since the pathway of production improvement is higher productivity. "Forest-saving agriculture" may be even more appropriate term,

GROWTH IN WHEAT PRODUCTION & AREA

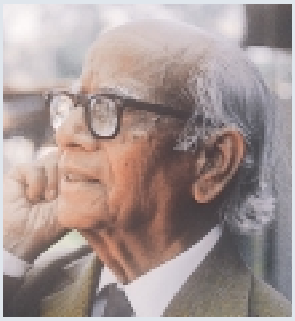


since agricultural expansion is often at the expense of forest area. Such phenomenal progress has been possible because of the introduction of mutually reinforcing packages of technology, services and public policies through the High Yielding Varieties Programme introduced by the Government of India in 1966. Yield improvement in wheat is one of the most exciting adventures in the field of agricultural science not only in our country but in the entire world.

B.P. Pal initiated the wheat improvement programme at the Indian Agricultural Research Institute (IARI), New Delhi. The emphasis of the programme of IARI was directed to achieve both disease resistance and yield. This ultimately resulted in varieties like NP 809 possessing a broad spectrum of resistance to stem, stripe and leaf rusts, and NP 824 possessing ability to respond to about 50 kg of nitrogen. In 1954, a research programme was started for developing non-lodging and fertilizer responsive varieties of wheat. With the earlier tall varieties it was difficult to get economic response to the application of mineral fertilizers and adequate irrigation water. Average wheat yields stagnated at less than 1 tonne per ha. This is why the breeding of non-lodging varieties was accorded a high priority during the fifties, when the country had taken to the path of expanding the area under irrigation and manufacturing of mineral fertilizers. Unfortunately, short and stiff straw was always associated with short panicles and fewer grains.

The breakthrough came in March, 1961, when a few dwarf spring wheat strains possessing the Norin-10 dwarfing genes, developed by Norman E. Borlaug in Mexico, were grown in the fields of IARI. Their phenotype was most impressive. They had reduced height and long panicles, unlike the earlier hybrids between *T. aestivum* and *T. compactum* and *T. sphaeroccum* and the induced erectoides mutants in which short height was coupled with small panicles. In 1964, a National Demonstration Programme was started in farmers' fields both to verify the results obtained in research plots and to introduce farmers to the new opportunities opened up by semi-dwarf

B.P. PAL



Benjamin Peary Pal (1906-1989) was born in a Hindu family at Mukandpur in Punjab on May 26, 1906. After early education in Yangon, Myanmar, Pal moved to Cambridge and received his doctorate degree in 1933. After returning to India, he joined the Imperial Agricultural Research Institute at Pusa, Bihar (now IARI, Delhi) as Second Economic Botanist and rose to become the Institute's Director. He was the first Director-General of ICAR. Pal is known for his work on breeding wheat variety (New Pusa 809) resistant to all the three types of rust disease. He also introduced a high degree of resistance to the smut disease. He is responsible for starting the All India Coordinated Research Projects for important Indian crops. It is through his initiative that the National Bureau of Plant Genetic Resources came into existence. Pal was an institution builder, able administrator and a policy maker. He groomed a large number of scientists, who later became leaders in agricultural research in India and abroad. He had a passion for ornamental plants and wrote authoritative books on roses. Many of the rose varieties bred by him are well-known.

B.P. Pal was a painter of landscapes and encouraged the arts. He was elected to the Fellowship of INSA in 1946 and to Presidentship 1975. He was a foreign member of the All Union Lenin Academy of Sciences and a Fellow of the Royal Society, London. He was a humourous person and effused warmth.

varieties for improving very considerably the productivity of wheat. When small farmers, with the help of scientists, harvested over 5 tonnes of wheat per hectare, its impact on the minds of other farmers was electric. The clamour for seeds began and the area under high yielding varieties of wheat rose from 4 ha in 1963-64 to over 4 million ha in 1971-72. This was because of the bold decision taken in 1966 at the instance of C. Subramaniam, the then Minister for Food and Agriculture, to import 18,000 tonnes of seed of the Mexican semi-dwarf varieties, Lerma Rojo 64A and Sonora 64.

The introduction of Lerma Rojo 64A and Sonora 64 was followed by the release of Kalyan Sona and Sonalika, selected from the advanced generation material received from Mexico. Further, hybridization between Mexican strains and Indian varieties resulted in many high yielding and rust resistant strains in different parts of the country. Mutation breeding for changing the red grain colour of Lerma Rojo 64A and Sonora 64 led to the production of Pusa Lerma and Sharbati Sonora. Crossing the semi-dwarf *T. aestivum* material with *T. durum* varieties produced semi-dwarf *T. durum* varieties like Malavika. In all cases, attention was paid to disease resistance and *chapati* making quality of the grain. Above all, the dwarf wheats would never have expressed their yield potential, without appropriate agronomic practices such as shallow seeding and giving the first irrigation at the crown root initiation stage.

Anticipatory research to avoid potential environmental problems was strengthened and a wide variety of high yielding strains possessing resistance or tolerance to the principal disease-causing organisms were developed. This underlines the fact that agricultural scientists were fully alive to the need for conducting an action-reaction analysis while introducing new technologies. Such awareness led to intensified efforts in varietal diversification and to the pyramiding of genes for tolerance to biotic and abiotic stresses. This is why wheat production had continued to show an upward trend during the last 35 years. The Indian wheat varieties Sonalika, WL 711, HD 2009 and HD 2172 are also popular in other countries like Bangladesh, Pakistan, Nepal, Bhutan, Afghanistan, Sudan and Syria. In Sudan, wheat var. HD 2172, grown in 90% of the wheat area, has paved the way for self-sufficiency in food grains.

The remarkable speed with which the high yielding varieties were identified from the initial Mexican material and later developed within the country was the result of the multi-location testing and inter-disciplinary research organized under the All India Coordinated Wheat Research Project of the Indian Council of Agricultural Research (ICAR). The coordinated wheat project is an outstanding exercise in meaningful, international and interdisciplinary cooperation. We salute B.P. Pal, who initiated both organized wheat breeding and coordinated varietal testing programmes in the country. Breeding efforts alone would not have borne fruit but for the outstanding support given by plant pathologists, agronomists, soil chemists and specialists in other disciplines. In short, the participants in the wheat research programme functioned like members of a symphony orchestra. Such harmony and cooperation led to historically path breaking results. Advances in wheat production also serve as an illustration of the value of fusion between political will and scientific skill. But for the political action taken by C. Subramaniam, scientific results might have just remained in the laboratory.

Rice: Systematic breeding of crop varieties which can respond to higher levels of plant nutrition started in India in 1952 when at the instance of Dr. K. Ramiah, a programme for incorporating genes for fertilizer response from temperate japonica rice varieties from Japan into indica strains was initiated at the Central Rice Research Institute (CRRI), Cuttack. Major aim was to select from segregating populations of *indica x japonica* crosses, lines which showed the ability to utilize effectively about 100 kg of N per hectare. With the advent in the early sixties

of the semi-dwarf, non-lodging, relatively photo-insensitive indica varieties based on the 'Dee-Gee-Woo-Gen' dwarfing gene identified in China, interest in transferring genes for fertilizer response from *japonica* varieties waned. Semi-dwarf *indica* rices like Taichung Native 1, IR8 and Jaya provided the initial material for the High Yielding Varieties Programme. In later breeding experiments, tropical japonicas from Taiwan also proved useful as parents.

Introduction of 'Dee-Gee-Woo-Gen' dwarfing gene from semi-dwarf, short duration, day neutral, fertilizer responsive var. *Taichung Native* 1 in our tropical rice resulted in crossing the yield barrier as the yield jumped from 3 tonnes/ha to 7 tonnes/ha. Now the country has a large number of high-yielding rice varieties suitable for cultivation under irrigated and rainfed conditions. India is the second country in the world to commercialize hybrid rice technology. Hybrid rice provides further yield advantage of 1.0-1.5 tonnes/ha. Wide cultivation of high yielding varieties and hybrids have helped in increasing rice production from about 40 million tonnes to over 80 million tonnes during the last three decades.

Seed production in hybrid rice.

Maize and Millets: Spectacular successes have also been achieved in improving the yields and production of maize, sorghum, pearlmillet and ecofriendly small millets – finger millet, foxtail millet, kodo millet, little millet, prosomillet and barnyard millet. India is the first country to develop hybrids in pearlmillet (bajra) which resulted in an increase in production from 2.84 million tonnes in 1950 to nearly 8.72 million tonnes in 1995. The newly developed hybrids are predominantly suitable for drought prone areas of Rajasthan. The crop, however, suffers from a serious downy mildew disease. Good progress has been made in developing extra early



heterotic mildew resistant hybrids and composites to mitigate the losses caused by this disease.

Sugarcane: India is the leader in sugarcane research. Remarkable improvement in yield, quality and ecological adaptation has been achieved by crossing the cultivated species with wild relatives and making intergeneric crosses with bamboo, sorghum and maize. This pioneering work was initiated by Sir T.S. Venkataraman in the 1940's at the Sugarcane Breeding Institute, Coimbatore which was initially established as Sugarcane Breeding Station in 1912. The new sugarcane varieties improved the productivity from 34 tonnes/ha to 63-100 tonnes/ha making India the largest producer of sugar in the world. Our current production of sugar is more than 13.4 million tonnes. To overcome the problem of 'seed' quality micropropagation technology has been developed to produce nearly 78000 plantlets (in vitro) from a single explant in less than six months. Our sugarcane varieties like CO 419, CO 527 and CO 6806 are also very popular in African and South-East Asian countries.

Grain legumes constitute a major source of food in India.

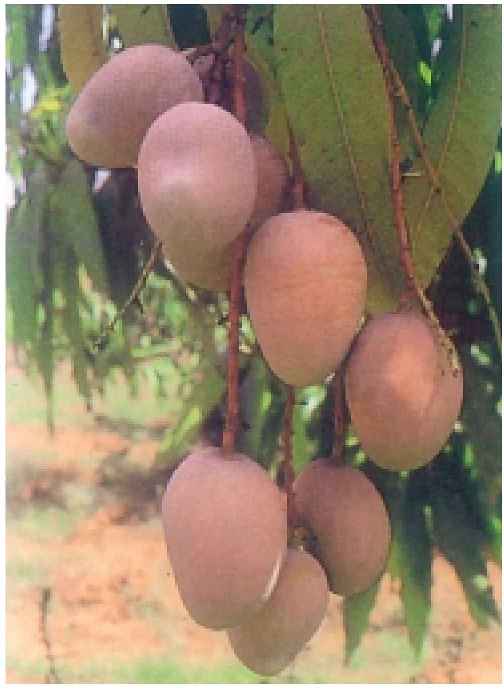


Oilseeds and Grain Legumes: Groundnut, rapeseed-mustard, sesame, linseed and castor are our main oilseed crops. In 1951 India was producing 5.16 million tonnes of oilseeds, but the present yields have risen to 20 million tonnes. This achievement, a result of research oriented 'Technology Mission on Oilseeds' launched by the country in the mid eighties, has made the country self sufficient in oilseeds. A similar technology mission has been launched for improving the production of grain legumes (pulses) to meet the dietary requirement of the largely vegetarian population of the country. Our production of grain legumes has improved only marginally during the last fifty years.

Cotton and Jute: India has the distinction of being the first country to have developed and grown hybrid cotton commercially. These hybrids give the finest-quality of cotton with spinning performance of 120s counts, comparable with the best in the world. Supported by the high yielding varieties and hybrids and IPM practices the production of cotton in the country has grown from 2.75 million bales in the fifties to 12.18 million bales last year, from about 7.5 million ha cotton area. The country has also developed eco-friendly coloured cottons through hybridization and mutation breeding. The coloured cottons will reduce the hazards of using azo-dyes. In addition, India produces 8.6 million bales of jute fibre, a substantial increase from 1.6 million bales about 50 years ago. Introduction of high yielding varieties and hybrids and improved agronomic practices are mainly responsible for the increased production. A major emphasis is on developing value added

products from jute fibre like fine yarn, blended yarn and speciality fabrics.





Left: India is a major centre of diversity in banana, over 70 cultivars are grown here.
Right: Regular bearing mango hybrid Arka Neelkaran.

Horticulture

India enjoys an enviable position in the horticultural map of the world as almost all types of fruits, vegetables, spices and condiments can be grown. India is the second largest producer of fruits (40 million tonnes) and also second largest producer of vegetables (72 million tonnes). India has also made a remarkable progress in flower production and is heading towards *Hi-Tech* practices. Although, horticulture has been practiced in India since Vedic times, organized research on horticulture started about 40 years ago with the establishment of a separate Division of Horticulture at the IARI, New Delhi and of the Indian Institute of Horticultural Research (IIHR), Bangalore. Now the country has 19 independent research institutions and 17 coordinated programmes for research on horticultural crops. Development of high yielding varieties and hybrid fruits and vegetables has contributed to a phenomenal growth of 11.2% and 5.6% respectively during 1991-96 period. India is the largest producer of mango, banana, sapota and acid lime. In grapes India has recorded the highest productivity per unit area in the world. Among the vegetables India occupies the first position in cauliflower and second position in onion and third in cabbage.

Mango: Mango, the king of fruits, is the most important fruit crop of India. It is also a major centre of diversity in mango which is believed to have originated in the Indo-Burma region. The first large orchard, known as *Lakhi Bagh*, as it had one lakh (0.1 million) plants, was planted by Akbar the Great in the 16th Century. Since that time mango is widely cultivated. Nearly 1200 varieties of mango have been identified which are being maintained and evaluated in field gene banks at different locations. These collections have provided important gene pools for regular bearing, crop duration, extended shelf-life and a wide range of pulp quality and flavours. Alternate bearing and mango malformation are two major problems in this crop. A singular achievement has been the development of dwarf and regular bearing hybrids through extensive breeding work carried out at IARI, New Delhi and IIHR, Bangalore. These hybrids can be planted in close spacing in high density orchards, accommodating 1600 plants/ha, which yield more than ten times per unit area than the conventional varieties.

Citrus: Citrus is the third largest group of fruit crops of India with a production of 2.98 million tonnes from 0.37 million ha. The major citrus fruits in India are mandarin orange, sweet orange and acid lime. More than 500 accessions of citrus are being maintained in field gene banks at different locations. Evaluation of the available

gene pool has helped in identifying promising root stocks, sources of resistance to pests and pathogens and tolerance to salt and drought. Salt tolerant species have been shown to exclude chloride uptake. Hybrid from Rangpur lime x trifoliate orange is a promising rootstock for mandarin and sweet orange imparting resistance to *Phytophthora* and nematodes.

Banana: India is the major centre of diversity in banana, the fourth important source of food after rice, wheat and milk. Banana has been grown in India for over 4000 years. The country produces 10.4 million tonnes of fruit from 0.39 million ha. Over 70 cultivars of banana are grown in the country depending on regional preferences. Some of these are low yielders but fetch high prices on account of their quality. Efforts are being made to improve their yield as well as quality. Highly promising hybrids have been developed with improved bunch weight (14-16 kg) and high degree of resistance to *Fusarium* wilt.

Micropropagation of banana *in vitro* has helped in establishing high density plantations supported by drip irrigation giving higher economic returns. Viral diseases, particularly banana bunchy top virus are serious problems. Sensitive diagnostic techniques based on monoclonal antibodies and c-DNA probes have been developed to index and provide healthy planting material of uniform quality.

Potato: Potato was introduced to India about 400 years ago. During the last fifty years, area under potato has grown from 0.2 million ha to nearly 1.0 million ha but production has shown a dramatic increase from one million tonnes to 22 million tonnes. This has been made possible through the introduction of innovative 'seed-plot' technique for producing disease-free seed, development of high yielding varieties for cultivation under different agro-ecologies and improved agronomic practices. Instead of the conventional tuber, potato seed referred to as true potato seed (TPS) has been used in Tripura. In some parts of the country, notably Gujarat, potato yields are about 65 tonnes/ha, which is 50 per cent more than those obtained in the Netherlands.

Other Tuber Crops: Tuber crops are the most efficient producers of carbohydrates per unit area and time. Cultivation of high yielding varieties and improved management practices have increased cassava (tapioca) productivity from 10 tonnes/ha to more than 30 tonnes/ha in early seventies in Tamil Nadu, leading to improved turnover of cassava based cottage-scale starch and sago industry.

Plant Genetic Resources

The Indian sub-continent is an important centre of origin and diversity of agri-horticultural crop species and their wild relatives. Nearly 160 domesticated species, 350 species of their wild relatives and over 800 species of ethnobotanical interest are native of this region. The significance of diversity can be judged from the fact that out of the 80,000 rice varieties 50 per cent are found in India. Collection, conservation and utilization of plant genetic resources were initiated at the IARI, New Delhi in 1945 by the visionary plant scientist Harbhajan Singh. Realizing the importance of this initiative, the country established a National Bureau of Plant Genetic Resources (NBPGR) in 1976. To conserve and utilize the valuable germplasm, a gene bank has been developed at NBPGR for long term storage of more than one million accessions. At present the facility holds about 145,000 accessions in seed repository, 800 accessions in tissue culture repository and 1000 samples cryopreserved in liquid nitrogen. The NBPGR is also responsible for the long-term conservation of global base collections of several crops.

Natural Resources and Agroforestry

Soil and water are the vital natural resources for optimizing agricultural production. The country is, however, facing serious concerns of reduction in arable land due to urbanization, annual loss of nearly 5,334 million tonnes of soil due to erosion, and depleting water resources. For research on cropping systems, nutrient management, water management, soil man-

agement and agroforestry, the country has established 13 national research institutions and 15 coordinated programmes. These efforts have helped in delineating 20 agro-ecological regions (AERs) and 60 sub-regions based on physiography, soil and period of crop growth. Cropping systems research has identified sustainable multiple cropping systems capable of producing up to 10-12 tonnes/ha/year from irrigated areas.

Water is a key input. Technologies have been developed for water harvesting recycling and economic usage. Integrated watershed management models for different agro-ecological regions and agronomic practices have been developed to conserve soil and water. Scientific approaches have been developed to stabilize sand-dunes by introducing tree species like *Acacia tortilis* (from Israel) which establish successfully in sand-dune affected areas.

Agroforestry provides an ideal approach for the optimum utilization of natural resources like water, soil and sunlight. Agroforestry has been in practice for a long time in India. Growing of tea, coffee, ginger, turmeric and cardamom in the shade trees and intercropping with trees like coconut are common in the tropical regions. Through research efforts indigenous and exotic species of plants have been identified for agri-horti-silvi-pastoral, silvipastoral, agri-silvi-pastoral and agri-horticulture in different agroecological regions. Agri-silvi combination of *Acacia nilotica* and wheat or chickpea has been found suitable for improving the productivity of marginal and dry areas. Various multipurpose tree species of *Acacia, Albizia, Azadirachta, Butea, Casuarina, Dalbergia, Hardwickia* and *Tecomella* have been recommended for agroforesstry in different agro-climatic regions of the country and for achieving sustainable productivity from wastelands.





Top: Variability in maize in North-East India. Above: Water harvesting in the Thar desert of Rajasthan.

Plant Protection

Biotic stresses are a major constraint in achieving full yield potential of crop plants. The losses due to weeds, diseases and pests have been estimated to be around 40% in the tropics and semitropics. If the post-harvest losses (15-20%) are also added, the situation becomes even more alarming. For sustainable agriculture, in an environment-conscious world, the growth-reducing factors like pests, pathogens and weeds have to be managed through eco-friendly measures, supported by judicious use of chemicals to maintain high economic returns without disturbing

the ecological balance. Therefore, integrated pest management (IPM) has been identified as one of the key technologies to increase crop productivity, as it is economical, ecofriendly and suitable for Indian farming systems where agricultural holdings are relatively small and the practice of intercropping of diverse crops is common. IPM practices involve need based application of chemical pesticides, use of botanical pesticides like neem products, use of resistant varieties and release of biocontrol agents. These have been developed for ecofriendly management of pest and diseases of rice, cotton, sugarcane, maize, oilseeds, pulses, citrus, grapes and vegetables.

Use of resistant varieties has been very successful in managing plant diseases. In the 1950's and early 1960's rust diseases of wheat used to result in 10% loss in yield. But now these diseases cause negligible damage due to deployment of resistance genes for wheat rust management. This has been achieved through extensive collaborative research efforts for identifying genes imparting resistance to different races of the rust pathogens and their deployment in different wheat-growing areas depending on the virulence of the prevalent races of the pathogens. If the losses due to rust pathogens were to continue, we would have been losing nearly seven million tonnes of wheat annually. It is a continuing effort. Researches are in progress for pyramiding genes like Lr 24, Lr 28 and Lr 19 for leaf rust resistance in wheat through molecular marker assisted selection as these genes are phenotypically indistinguishable. Resistance genes have also been identified in other crops for resistance to fungal, bacterial and viral pathogens.

***Cryptolaemus montrouzieri* predates on mealybugs which are a menace to fruit crops.**



Recent biotechnological developments provide powerful and novel mechanisms for the management of biotic stresses. The introduction of crystal protein gene (cry gene) of *Bacillus thuringiensis* (Bt) into crop plants for developing pest resistant varieties is a major breakthrough. At the IARI, New Delhi a mutated gene encoding *Bt-cry* 1Ac d-endotoxin has been found to be highly effective against cotton bollworm and rice yellow stem borer. Transgenic tobacco and other crop plants expressing trypsin inhibitor gene from cowpea have been shown to have resistance to coleopteran, lepidopteran and orthopteran pests. Over expression of chitinase or glucanase, the fungal cell wall hydrolyzing enzymes, in transgenic *Brassica juncea* has shown promise of developing resistance against *Alternaria* which is a limiting factor in the production of this crop.

Biotechnological approaches are most useful for the management of viral diseases of plants, as transformation of plants with genes of viral origin imparts resistance to infection by viruses. Coat-protein (CP) gene of plant viruses has been found to be best for developing resistance against homologous viruses. Genomes of a large number of viruses, particularly those belonging to Gemini- and potyvirus groups, have been cloned to identify specific genes for use as transgene in developing resistant plants. Tobacco plants transformed with the CP gene of potato virus Y (PVY), which causes severe diseases in a variety of crops including tobacco, developed varying degree of resistance to infection by PVY.

Veterinary Sciences

India is very rich in livestock diversity. In terms of numbers we have over 200 million cattle, 76 million buffaloes, 46 million sheep, 110 million goats, 11 million pigs, 1.9 millions equines, 1 million camel and 310 million poultry. Animal wealth has also been an important component of Indian agriculture from times immemorial as important sources of nutrition, draught power and organic recycling. There has been a quantum jump in milk production from 17 million tonnes in 1950 to nearly 75 million tonnes in 1999, making India the top milk producer in the world. Similar increase in the production of eggs and broilers has been achieved.

Improvement of animals has been practiced in India from the days of *Matsya Purana* which deals with the selection of efficient bulls. Since then, breeding and selection of animals for different agro-ecologies has resulted in vast diversity in our livestock and poultry. However, organized animal research started with the establishment of Imperial Bacteriological Laboratory at Pune in 1889 which shifted in 1893 to Mukteshwar in the Kumaon Himalayas and later became the Indian Veterinary Research Institute (1947). We now have a network of 18 national research institutions and 16 coordinated programmes for conducting extensive research on different species of domestic animals, animal products and animal health.

India has worlds' best breeds of dairy buffaloes, draught cattle, carpet wool sheep and goats. We also have rare species of yak, mithun, pigmy hog and wild buffaloes. The country has established a National Bureau of Animal Genetic Resources with headquarters at Lucknow to work in collaboration with other institutions for evaluation, characterization, conservation, management and improvement of our rich animal genetic resources. The Bureau is developing cytogenetic profiles of livestock and databases for breed conservation and utilization. Chromosome profile has been determined for cattle (*Bos indicus*), buffalo (*Bubalus bubalis*), goat (*Capra hircus*), sheep (*Ovis aries*), horse (*Equus domesticus*), donkey (*Equus asinus*), single humped camel (*Camelus dromedarius*), pig (*Sus scrofa*), yak (*Bos grunniens*) and mithun (*Bos frontalis*).





Top: Karan Swiss cow, a cross between Brown Swiss and Red Sindhi/Sahiwal.
Above: The world's first in vitro fertilized buffalo calf.

Crossbreeding with exotic breeds has produced new improved genotypes. In cattle new genotypes Karan Swiss (Brown Swiss x Red Sindhi or Sahiwal) and Karan Fries (Friesian X Tharparkar) are giving an annual lactation of 3,385 and 3,820 litres respectively. Frieswal (Holstein X Sahiwal) yield even



An elite Karan Fries cow with its ten calves produced by super ovulation and embryo transplant technology.

better (4000 litres) at mature lactation. This programme has helped in improving milk production in the country. Similarly, improved genotypes have been developed for sheep, goats, rabbit and poultry. The Indian livestock germplasm resources have also been used for developing new breeds in Australia, Europe, South-East Asia and South America.

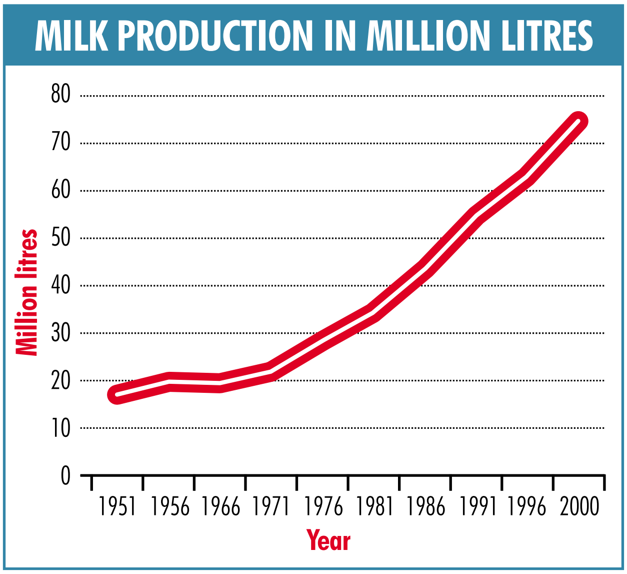
Significant advances have been made in cryopreservation of buffalo semen, *in vitro* maturation and *in vitro* fertilization of buffalo oocyte and embryo transfer technology (ETT). Through ETT, a superior bovine female can be made to produce 5 to 10 calves a year and up to 50 calves or more in its life time. ETT is also successful in buffalo, sheep and goat.

Disease diagnosis, disease monitoring and surveillance procedures, supported by improved vaccination programme have helped in increasing animal production. The country has produced vaccines to guard against the diseases like: anthrax, haemorrhagic septicaemia, blackquarter, fowl cholera, Ranikhet disease, swine fever, rabies, foot and mouth disease, sheep pox, goat pox, fowl pox, clostridial diseases in sheep, theileriosis, canine distemper and equine influenza. The laboratories in Bhopal and Bangalore have appropriate microbial containment facility for producing diagnostic reagents and vaccines against contagious diseases like foot and mouth disease. The laboratory in Bangalore also serves as referral laboratory and conducts epidemiological studies on rinderpest and rinder-pest like diseases, with the help of a network of 32 laboratories established to monitor these diseases.

Rinderpest was the most serious disease of ruminant animals in the country up to 1950 when an eradication programme was started entirely by indigenous efforts using vaccines developed by the Indian Veterinary Research Institute (IVRI). By 1960, mortality rate was reduced by 80-90%, which greatly helped in providing the additional draught power required during the 'green revolution' years. By 1995 the entire country was free of this dreadful disease and the fresh vaccinations were stopped in 1997. The vaccines developed in India have also been used in other countries in rinderpest eradication programme.

Fisheries

Fish is a dynamic self-renewable natural resource. It is the most economical source of animal protein and an important health food. Fisheries constitute a unique sector offering animal protein to a wide cross-section of society from a price ranging from Rs. 10/kg to as high as Rs.700/kg. High fecundity (up to 1 million eggs) and fast growth rate (growth coefficient often >1.0) have no parallels in other animal protein sources like the livestock, including poultry. These advantageous biological characteristics of fishes offer considerable scope for increasing production and achieving nutritional security to a large extent. With the availability of 2.4% of global land area, India has to nourish and sustain 16% of the world population; hence its dependence



on aquatic food production is obvious.

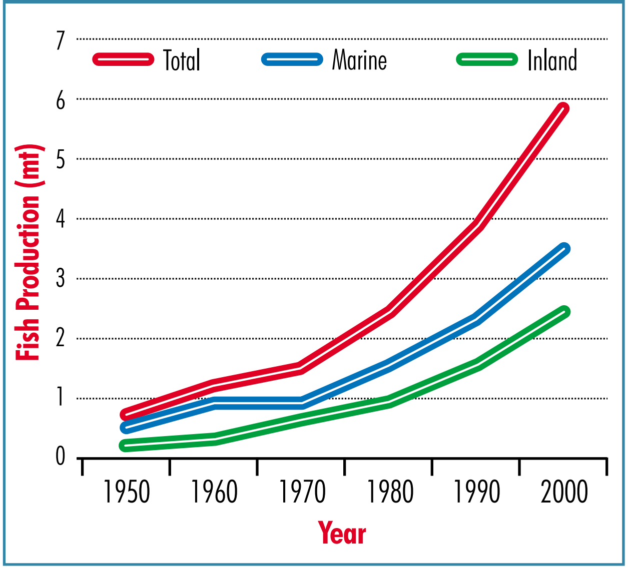
From the vast and diverse aquatic resources of India 0.8 million tonne fish were captured during 1950s; even then, we exported about 20,000 tonnes of fish, mostly in dried form, and earned Rs. 25 million. The country has established 8 national fisheries research institutions, each with specific mandates to cater to all areas of fisheries research. Thanks to these institutions and their research contributions, we produce 5.8 million tonnes of fish and export about 0.4 million tonnes of shrimps, mostly frozen and canned, and earn a net foreign exchange of Rs. 55 billion. Briefly, fish production in our country has grown more than five times, fisheries contribution to the GDP of India also increased 3 times, a growth arguably one of the highest among the food production sectors.

The following land-mark scientific contributions have helped in achieving this remarkable enhancement in fish productivity. (i) The then Central Inland Fisheries Research Institute, Barrackpore published the first paper on the success in induced breeding of carp in 1957. Subsequently, technologies on induced breeding and larval rearing were developed for a number of species of carps. These research developments paved the way for the current annual freshwater carp production of >1 million tonnes. (ii) The Central Marine Fisheries Research Institute (CMFRI) developed the hatchery technology of penaeid shrimps during 1973-78 and commercial scale production started in the late eighties. In 1999-2000, the country has exported farmed shrimps worth $ >1 billion. CMFRI has also developed models for (a) stock assessment and population dynamics of multispecies, multigear fish resources in tropical waters, (b) fishery forecasting, and (c) in 1980 the Central Institute of Fisheries Technology (CIFT) and the Bay of Bengal Programme (FAO), Chennai, designed a high opening trawlnet with the help of gear experts in India. The design revolutionized the capture fisheries sector. In two decades, all the trawlnets (1,50,000 in number in 1998) in the country are of high opening type. They are responsible for an annual fish harvest of >1.2 million tonnes. CIFT has also developed technologies for the production of chitin and chitosan from prawn shell waste for wide ranging applications in pharmaceuticals, textile, cosmetic and paint industry. Absorbent surgical sutures have been developed from gut collagen of fish by cross and polymer coating for use in microsurgery. These developments have paved the way for, what is hailed as Blue revolution or

Bull's Eye fish, a deep water resource with a vast potential.



FISH PRODUCTION IN INDIA



Aquaplosion in India. India has an enormous diversity of fish with 2,200 indigenous species. A National Bureau of Fish Genetic Resources has been established to develop a database on fish resources, preserve and maintain pure line fish stocks and breed fast growing hardy and high yielding fish varieties. These efforts will help in sustaining the blue revolution.

The Central Institute for Freshwater Aquaculture has cultured pearls in freshwater mussel and CMFRI has standardized pearl culture in *Pinctada fucata*, the most abundant pearl oyster in India. Technology has been developed to culture pearls in desired images and shapes.

Despite these the achievements in improving fishery production, the per capita fish availability is less (8 kg) than the world average (12 kg) and the quantity (11 kg) recommended by WHO. During late 1980s, aquafarming was undertaken by progressive fish-farmers in the east coast. By 1993, this kind of aquaculture activity led to farming of shrimp to the extent of 0.14 million ha and production of 0.83 million tonnes. We have thus used less than 10% of available area that can be brought under aquaculture. Of the 297 species known to be suitable for aquaculture, Indian farmers have mastered the technology for mass production of only 15 species so far. For another 20 and odd species, mass culture techniques are being developed by the country's research institutions.

Challenges Ahead

The transition from a "ship to mouth" existence to one of food self-sufficiency at the prevailing level of purchasing power achieved during the last 50 years is perhaps one of the greatest human accomplishments since the dawn of agriculture 10,000 years ago. Such a transition was achieved through pioneering agricultural research and a multipronged strategy consisting of (a) increased food production, (b) building grain reserves, (c) operating an extensive public distribution system, (d) protective social security measures like food for work, nutritious noon meal and employment guarantee, and (e) land reforms and asset creation measures. However, we continue to force the challenge of endemic hunger as over 200 million children, women and men are under nour-

Open water fishery resources in India and their modes of fishery management

Resource	Resource size	Management mode
Marine jurisdiction (mKm^2)	2	-
Coastline (km)	8,219	-
Brackishwater (m ha)	2	Aquaculture
Rivers (km)	29,000	Capture fisheries
Mangroves (ha)	356,000	Subsistence
Estuaries (ha)	300,000	Capture fisheries
Estuarine wetlands (bheries)(ha)	39,600	Aquaculture
Backwaters/lagoons (ha)	190,500	Capture fisheries
Large & medium reservoirs (ha)	1,667,809	Enhancement (stock & species)
Small reservoirs (ha)	1,485,557	Culture-based fisheries
Floodplain wetlands (ha)	202,213	Culture-based fisheries
Upland lakes (ha)	720,000	

ished largely due to inadequate purchasing power arising from inadequate opportunities for skilled employment. The time is now ripe to take the final steps essential for the total elimination of hunger. The opportunity for a productive and healthy life for every individual would depend on the success of our strategies for hunger elimination.

The population of India is growing at the rate of 1.8 percent per year. If this trend continues, our population will double itself in less than 40 years. Only Kerala, Tamil Nadu, Goa and Mizoram have so far achieved a demographic transition to low birth and death rates. Andhra Pradesh is now on the verge of achieving the goal of population stabilisation. Besides population increase, improved purchasing power among the poor will enhance the demand for food, since under-nutrition and poverty go together. There is still a widespread mismatch between production and post-harvest technologies. In perishable commodities such as fruits, vegetables, flowers, meat and other animal products, this mismatch is often severe, affecting the interests of both producers and consumers.

Out of every three ha of cultivated land in our country, two ha are under rainfed agriculture. Therefore, top priority should be given to improving the productivity and stability of rainfed agriculture.

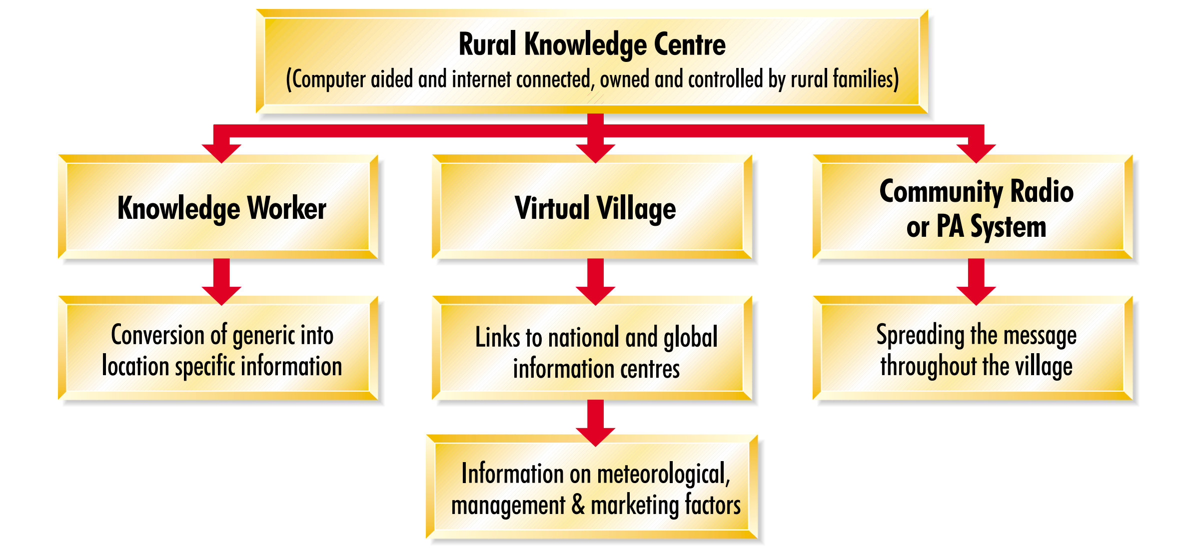
Looking Ahead

A major accomplishment of Independent India is the development of a dynamic national agricultural research, education and extension system. We have a well established network of State Agricultural and Animal Sciences Universities and national research institutions and All-India Coordinated Research Projects supported by the Indian Council of Agricultural Research. Therefore, we have opportunities to produce food and other agricultural commodities, particularly fruits and vegetables, not only for our country but also for international markets.

The gap between potential and actual yields is high in a majority of farming systems. In most of the crops, the present average yield is just one third of the achievable yield. Therefore, a massive effort is required to launch a new revolution in farming, through cost saving and efficient technologies both for production and post-harvest management. This would require adoption of the following strategies

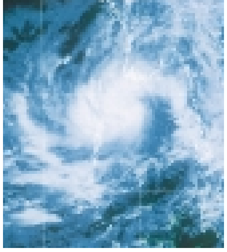
- Defending the gains already made by adopting integrated natural resource management so that present production does not erode future prospects. This is particularly required for the traditional 'green revolution' areas.
- Extending the gains to areas which have been bypassed by the 'green revolution' technologies.
- Making new gains: The need for making new gains is urgent. This can be achieved by utilizing the available agro-climatic/soil maps, watershed/ wasteland atlasses, GIS mapping and remote sensing capabilities for developing improved and integrated crop-livestock-fish farming system, and developing infrastructure for value addition to farm products at the village level. These changes will provide opportunities for off-farm employment and income generation.
- Institutional and infrastructural support is essential for higher agricultural production. There is an urgent need for providing efficient irrigation, power supply, rural roads, cold storages, godowns and food processing units supported by assured and remunerative marketing as developed by the successful dairy and marketing cooperatives.
- Increasing rural income through (a) recognition and reward to the past and ongoing contributions of farm families in improving, selecting and conserving crop genetic resources as envisaged in the Protection of Plant Varieties and Farmers' Rights Bill, 2001, and (b) increased agricultural exports. To increase agricultural exports we will need greater investment in post harvest technology and infrastructure for meeting the requirements of sanitary and phytosanitary measures, ISO 9000, 14000 and Codex Alimentarius standards.

RESTRUCTURING AND RETOOLING OF EXTENSION SERVICES



For the success of the above strategies the country will require restructuring and retooling of extension services for an era of precision farming by establishing Rural Knowledge Centres and retraining of existing extension workers as Rural Knowledge Workers. The legacy of the past 50 years gives us confidence that our farm women and men will overcome difficulties and capitalize on opportunities and help the country to realise Gandhiji's vision of a hunger free India in the early part of this century.

The pictures, and the data for graphs and tables used in this chapter have been provided by ICAR.



CHAPTER XXII

Dairy Development in India

During the last three decades, our nation's milk producers have transformed Indian dairying from stagnation to world leadership. During this period and before, science and technology (S&T) have played a critical role in supporting our farmers efforts. During the next decade, that role will be further enhanced as we face a number of new challenges.

The dairy cooperative movement has been central to the development of dairying in India. The inspiration for this movement was the success of the Khaira District Cooperative Milk Producers' Union -- better known as Amul. Founded in 1946 in response to the exploitation of district's dairy farmers, Amul grew rapidly from its initial base of two societies and two hundred litres of milk. That growth, however, posed a challenge that threatened its existence: flush season production of milk exceeded the demand. Yet the cooperative's success depended on accepting the farmers' milk year round.

At that time the advanced dairying nations conserved milk by conversion into powder and butter. This could either be sold as products, or combined with fluid milk to extend the supply during the lean season when demand outstripped production. Experts from the North pronounced buffalo milk as unsuitable for conversion into powder. It couldn't be done, they said. This provided the opportunity for the first major Indian scientific and technological breakthrough. The Amul staff, led by the then General Manager; solved the problems by producing powder from buffalo milk. It would not be an exaggeration to say that this advance in the technology saved Amul and, with it, ensured the future of the as yet unborn Indian dairy cooperative movement. Today it is one of the most successful and the largest cooperative dairy enterprises in the whole of Asia.



Photo: H.Y. Mohan Ram

Since that time, S&T have produced a large number of breakthroughs that have been critically important to the

development of Indian dairying. A wide variety of institutions have contributed including the National Dairy Research Institute, Karnal, agricultural universities, veterinary colleges and, proud to say, the National Dairy Development Board (NDBD).

At the foundation of our dairy industry are the cows and buffaloes that produce most of our milk. India does have some excellent breeds. Among cattle, the *Sahiwal*, *Rathi*, *Gir* and *Red Sindhi* stand out as milk producers; for the buffalo, pride of place goes to the *Murrah*, *Mehsani* and *Jaffarbadi*. However, these recognized and superior breeds represent but a very small, though valuable, part of our national milch herd. The majority of our animals are nondescript with limited genetic potential.

The most efficient way to improve the potential of our nondescript cattle and buffaloes is through artificial insemination. It was only in the mid-1940s that a major breakthrough was made in this field with the use of antibiotics to ensure that semen would remain viable. Since that time, major advances have been made in semen extension, cryogenic preservation and distribution. Today, NDDB supports this effort through 14 Bull Mother Farms that produce and supply exotic breed bulls to semen stations throughout India. NDDB also directly supports 11 semen stations and has financed a network of 10,556 artificial insemination centres that annually deliver 5 million semen doses to cattle owned by members of 20,000 dairy cooperative societies.

Good genetic potential cannot be realized without good nutrition. In India we face an important challenge: ensuring adequate nutrition for our animals without competing with man for available land and agricultural commodities. The solution has been reliance on crop residues and byproducts. Working with Australian scientists, NDDB has developed several innovations that enhance nutrition directly and by improving digestibility and palatability: urea molasses blocks and urea treatment of straw both improve the diets of our dairy animals and help reduce the methane released into the atmosphere.

NDDB has also supported animal nutrition through the financing of 46 cattle feed plants and supporting these plants with quality control laboratory services. A useful innovation has been the development of protected feed technology which minimizes the degradation of protein and fat in the rumen. Mineral deficiencies are also a constraint to improved animal productivity. NDDB is supporting area surveys resulting in profiles that lead to targeted mineral mixtures to be used as supplements in cattle feeds sold to farmers in these regions.

FOOT AND MOUTH DISEASE (FMD) IS A MAJOR CAUSE OF REDUCED MILK YIELDS AND DIMINISHED DRAUGHT POWER IN INDIA. NDDB'S INDIAN IMMUNOLOGICALS IS THE LARGEST FMD VACCINE PLANT IN ASIA.

Last, but not least, animal diseases cost our nation's milk producers thousands of million rupees are lost annually in production. NDDB's efforts in this field are a matter of great pride. NDDB has developed a live tissue culture attenuated vaccine to control theileriosis, a blood protozoan infection that is usually lethal in European and crossbred cattle. This vaccine is the only one of its type commercially available in Asia.

Foot and Mouth Disease (FMD) is a major cause of reduced milk yields and diminished draught power in India. NDDB has pioneered the effort to identify the prevalent serotypes through analysis of Indian field isolates. In order to ensure that the vaccine would reach India's farmers, NDDB established a state of the art facility, Indian Immunologicals, which is the largest FMD vaccine plant in Asia.

Mastitis is another endemic disease that undermines the health and productivity of our national milch herd. It is estimated that more than 40 per cent of our cattle and almost 25 per cent of our buffaloes suffer from subclinical mastitis. NDDB has developed a simple diagnostic aid for its detection at a stage when therapeutic and control measures can reduce losses from decreased production.

Haemonchus controtus, India's dominant worm species, is a major cause of parasitic gastroenteritis which leads to poor growth, delayed maturity, reduced milk production, lengthened inter-calving periods and the death of young animals. Conventional treatment rquires forceful oral administration, placing difficult demands on both the farmer and the animal and the presence of a veterinarian. NDDB has developed medicated feed pellets that kill even drug-resistant worms without the need to restrain the animal. This should lead to far more widespread treatment of worms and lowered losses from parasitic gastroenteritis.

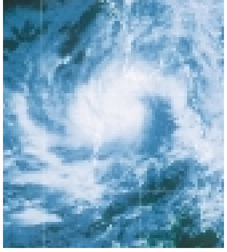
Milk production is, of course, only half of the story. The other half is the sale of milk and milk products that provides the highest returns to our dairy farmers. Here too, S&T have played an important role in development of products, processes, packaging, handling, transport and storage. Among the major breakthroughs have been:

- automation of *khoa* production, moving this process from the backyard to the modern dairy.
- design of the process technology and equipment for manufacture of *peda, gulab jamun, cchhana podo*, long-life *panneer* and other Indian milk products.
- development of continuous lines, including packaging, for fermented milk products like long-life *lassi, shrikhand, dahi* (yogurt)and *misti doi*.
- process technologies for production of Cheddar, Mozzarella and Emmental cheese as well as a variety of cheese spreads using both cow and buffalo milk.
- preservation of starter cultures for fermented milk products.
- process of manufacture of dry mixes for *gulab jamun* and frozen deserts.
- user-friendly milk testing kits.

As satisfying as the achievements have been, the real challenges lie ahead. Among the most important are:

- Ensuring steady growth in productivity while ensuring that dairying remains concentrated in our landless, marginal and small farmer communities.
- Using advanced breeding technologies to accelerate the development of our high potential Indian cattle and buffalo breeds.
- Developing quality control methods that are sensitive to the fact that our milk comes from large numbers of small producers.
- Ensuring increasing reduction in losses from endemic and epidemic diseases at costs our farmers can afford.
- Expanding the variety, improving the quality and maintaining the relative price of India's dairy products so that they can meet competition from around the world.
- Ensuring that the growth of the dairy industry contributes to enrichment of our environment while continuing to benefit low-income producers without compromising our nation's need for milk.

These and other challenges face the current and next generation of scientists and technologists. Their predecessors have built a solid foundation. The strength of that foundation is due in large part to the fact that India's dairy farmers have set the research agenda. Beginning with Amul during the 1940s, it was their need that inspired the work of our dairy scientists and technologists. It is the evolving needs of India's several million dairy farmers that will inspire those who follow.



CHAPTER XXIII

Chemical Engineering and Industry

Chemical Engineering vs Other Engineering Disciplines

Chemical engineering had a unique start, in contrast to the other engineering disciplines, in that right from the beginning it was a degree course. In other branches of engineering we had old institutions like Howrah College of Engineering, Kolkata; Guindy College of Engineering, Chennai; Poona College of Engineering, Pune; V.J.T.I., Mumbai; and Thomason College of Engineering (now University of Roorkee), Roorkee; which started with diploma courses and introduced degree courses later. The even more attractive feature was that universities took a lead and started courses in Chemical Engineering and Chemical Technology. These were essentially post B.Sc. Courses. In the early 1950's these courses became 4-year post Inter Science (subsequently Senior Secondary) courses. Since Chemical Engineering and Chemical Technology were taught by University Departments, research became important as these departments were measured with the same rigour as other sciences and liberal arts. Thus the PhD programmes were introduced quite early. Jadhavpur University (earlier called National College), Kolkata; Panjab University, Chandigarh; Andhra University, Vishakhapatnam; Banaras Hindu University (BHU), Varanasi; Calcutta University, Kolkata; Indian Institute of Science, Bangalore; University Department of Chemical Technology (UDCT), Mumbai took an early lead. Later A.C. College of Technology, Chennai; L.I.T. Nagpur; Annamalai University, Annamalai etc. came into existence. The UDCT was unique as it was planned by industrialists and philanthropists, with substantial financial support - consequently it was the first department to get autonomy under the provisions of the University Grants Commission and University of Bombay, Mumbai. Prior to the partition, Panjab University, Lahore, offered courses in chemical technology. Jadavpur has the distinction of conceiving and executing the first course in Chemical Engineering. BHU was a pioneer in courses in Chemical Technology. Prominent personalities that belonged to the period 1930-50 were S.C. Venkat Rao, G.P. Kane, P.S. Mene, Govind Rao, N.R. Kamath, G.S. Laddha and M.N. Rao.

A major event was the establishment in early 1950's of a series of Indian Institute of Technology (IIT) now six in all initially with the help of the then USSR, UK, USA, Germany. All these institutions opened chemical engineering courses and ushered in a major change, nationally and internationally.

Chemical Industry in India

Prior to 1947, India had hardly any chemical industry-the small explosives factory (at Kirkee, near Pune and Arvankandu, Nilgiris) and small single superphosphate plants, with attached sulphuric acid plants were small units with limited production. Bengal Chemicals in Kolkata was a pioneering group and had a nationalist academic entrepreneur Acharya Prafulla Chandra Ray (see Chapter on Torch-bearers)

as the key person in all respects. India's sugarcane industry needed phosphorus as a part of the fertilizer and this was supplied as single superphosphate. Sindri fertilizer plant was a second world war reparation gift and was based on coal from nearby fields and gypsum (which after partition had to be hauled all the way from places near Jodhpur in Rajasthan). There was no petroleum refining except for a tiny unit, processing 0.25 mtpa, in Digboi, Assam, based on local crude oil and to service the thriving tea gardens. The first three refineries (two in Mumbai and one in Vishakhapatnam) came up in early to mid 1950's and made a quantum change in the Indian scenario. The first planned fertilizer plant was of Fertilizer Corporation of India in Mumbai, adjacent to the refineries (now called RCF). The Nangal plant was really planned to utilize surplus cheap power from Nangal so that electrolytic hydrogen for ammonia became viable. Since there was no CO_2, ammonium nitrate (AN) and calcium ammonium nitrate became the chosen fertilizers. Ammonium nitrate could also be used as an explosive. Alas the surplus power became an illusion in early years of operation and technology change had to be brought in. The Nangal plant was also the first to start production of Heavy Water, required for nuclear energy programme.

Sugar industry provided cheap molasses and with the prevalent prohibition, ethyl alcohol became an attractive raw material. Late 50's and early 60's saw the emergence of the organic chemical industry in India but soon thereafter there was a serious deficit of ethanol. Nagaraja Rao and G.P. Kane played a key role in promoting the alcohol-based industries. However, surplus naphtha from refineries became a convenient raw material but even this became short in mid 1970's and became surplus again in 1990's. The discovery of the natural gas and crude oil in Assam, Gujarat and Bombay High brought a major change and a long Natural Gas pipeline called HBJ pipeline of about 1800 km length, from Bombay High to Jagdishpur in UP was established in 1980's. Later Natural Gas was discovered in Godavari coast also.

Textile Industry

India has enjoyed a high reputation in cotton textiles. Initially we thrived on spinning and weaving. After Independence, processed fabrics became important in India and the UDCT, Mumbai, played a pivotal role in this endeavour. The thriving textile industry needed chemicals like caustic soda, bleach liquor, dyes, pigments and a number of prominent textile houses, like Delhi Cloth Mill, Mafatlals, Sarabhai started chemical units to manufacture caustic soda, chlorine, dyes.

The need for rayon industry was felt in 1940's and NRC, Kalyan (near Mumbai), Century Rayon (Shahad, near Mumbai) came into existence where sulphuric acid, rayon grade caustic soda, were required and captive plants were established.

Soda Ash

Mithapur, near Okha port, Gujarat, saw the birth of the first major salt based industry and became an important Solvay plant in the global context. This unit was pioneered by Kapil Ram Vakil and later taken over by Tata Chemicals, where the truly outstanding chemical engineer Darbari Seth made monumental contributions.

Research Laboratories

Government of India took a major decision, just before Independence, to establish the Council of Scientific & Industrial Research (CSIR) and in chemical sector the pioneering laboratory was the National Chemical Laboratory (NCL), Pune, established in 1950. Prior to this the Nizam State, Hyderabad, had a Central Laboratory, later called Regional Research Laboratory (RRL), Hyderabad, by the CSIR, (presently called the Indian Institute of Chemical Technology). Many RRL's were subsequently established. From the chemical industries point of view the additional CSIR laboratories of significance were the Indian Institute of Petroleum, Dehra Dun; Central Salt and Marine Chemicals Research Institute, Bhavnagar; Central Electrochemical Research Institute, Karaikudi and

Central Leather Research Institute, Chennai. For drugs we have Central Drug Research Institute, Lucknow and Institute of Microbial Technology, Chandigarh. Much earlier we had, in the coal belt, the Central Fuel Research Institute, Dhanbad.

The above laboratories had many outstanding chemical engineers, chemical technologists and chemists. A specific mention must be made of K. Venkataraman (UDCT and NCL), B.D. Tilak (UDCT and NCL), both were contributors to the birth of the dyestuff industry in India.A distinguished galaxy of chemical engineers further enhanced our capabilities in diverse fields. This included some of our late Fellows: Y.Nayudamma, S.C.Bhattacharya, G.S.Sidhu, Hussain Zaheer and number of still active scientists.

Research in Nuclear Sciences and Nuclear Power

The establishment of Atomic Research Centre, Mumbai, now called Bhabha Atomic Research Centre (BARC), to honour the founder of nuclear research in India, Homi Bhabha, and other laboratories made a major impact for chemists and chemical engineers. This got buttressed with the establishment of Nuclear Power Plants, with the associated units for nuclear fuel and Heavy Water. Chemical engineers played a vital role in the above area as well as in the exploration of rare earths. (See write-up of DAE).

Defence & Space Research Establishments

The Defence Research and Development Organization (DRDO) requires a large number of chemical engineers, chemical technologists and chemists. Space research, particularly for rockets, required chemical engineers. Contributions to polymers and chemicals used in the space programme constitute vital inputs for the success of this endeavour.

Academic Research

As chemical engineering started in University Departments, research became an integral part of the activities from inception and a special mention should be made of the UDCT, Mumbai (which continues to occupy a prominent position) and the Indian Institute of Science, Bangalore. In later years IIT's became important centers.

The scientific contributions of Indian Chemical Engineers has been widely acclaimed both nationally and internationally. Among many such recognitions and awards mention may be made of Fellowship of the Royal Society, London to two of them.

Design and Fabrication Capabilities

In earlier years FACT, Kochi, and the Sindhri unit of FCI had some design capabilities. The creation of Engineers India Ltd (EIL) brought out a quantum change in India, particularly for petroleum refining and petrochemicals. EIL also carried out work overseas. A number of multinational companies and some Indian companies later entered into this business. Thus detailed engineering became world class.

International class mechanical design and fabrication facilities at Larsen & Toubro, Mumbai and BHPV, Vishakhapatnam, further strengthened the Indian position in putting up plants involving very high pressures and complicated designs.

Establishment of Indian Institute of Chemical Engineers

As in the case of the USA and UK, the Indian chemical engineers also thought it prudent to have a separate professional group of their own and this was realized in 1947 through sustained efforts of H.L. Roy in Jadavpur, Kolkata. A number of illustrious persons have been Presidents and these included R.R. Hattiangadi, who made major contributions in the cement industry from early 40's, G.P. Kane, G.S. Laddha, who did world class research in liquid-liquid extraction at A.C. College, Chennai, G.S. Kasbekar, who headed the first public sector integrated organic chemicals complex, Hindustan Organic Chemicals, Rasayani.

Industrial R&D

In the late 1950's, companies such as the National Rayon Corporation had design and development departments and executed some of their projects on their own. A similar situation existed in Delhi Cloth Mills. A number of technocrat entrepreneurs entered the Indian scene from 1960's onwards. The earliest case of world-class processes came from a qualified chemical engineer K.H. Gharda, Gharda Chemicals, where the first blue phthalcyamine dye was made, which was superior to the best available in the world. This was followed by several breakthroughs in speciality chemicals and more specifically agrochemicals. For a well-known herbicide, Isoproturon, a non-phosgene process was developed, even before the Bhopal disaster. This was the first such process globally. Many technocrat entrepreneurs have made the Indian scene vibrant.

The Indian Petrochemicals Corporation Ltd, (IPCL), had the unique distinction of having a Director, R&D, on Board of Directors, even before the commercial production commenced. Subsequently India's largest oil refining company, Indian Oil Corporation, Ltd. had created a place for R&D Director on the board. Shri Lov Raj Kumar deserves credit for spearheading these momentous changes. Hindustan Lever was the one of the earliest to have an R&D Centre and an R&D Director on Board. Ciba Research Center was established in Mumbai under Govindachari as the chief and made many valuable contributions. Alas, this unit was later folded up and the same fate was met by the Hoechst Research Centre in Mumbai.

Advent of Reliance Industries- A Phenomenon

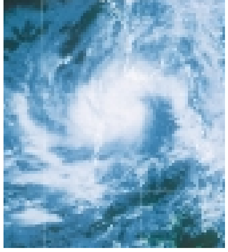
The Reliance group of Industries, changed the fundamentals of business in the chemical industry. To start with polyester filament plants were established with a daily capacity equal to the annual capacity of some pioneering companies. In the case of polyesters they have a unique global position of complete integration from basic raw materials *p-xylene*, terephthalic acid, ethylene, ethylene glycol, to finished fabrics and also resins.

The world's largest *p-xylene* plant, at Jamnagar and the world's largest greenfield petroleum refining company have been established in Jamnagar by the Reliance Industry, in record time and with lowest per unit capital investment. Indian chemical engineers have played a pivotal role in this gigantic exercise.

The chemical industry is the first science based industry and the first one to become global. More than 300 mtpa of some more than 1,00,000 chemicals are produced with a turnover of USD1.6 trillion. No industry has made as much impact on the quality of life as the chemical industry.

Concluding Remarks

Chemical engineering has contributed immensely to continuous processes, process integration and intensification, safe operations, astute scale-up. Chemical engineering is exciting, rewarding, challenging and edifying (and even entertaining!).



CHAPTER XXIV

ENGINEERING AND TECHNOLOGY FOR DEVELOPMENT

The Planet Earth has the unique feature of sustaining by the energy of the sun, the marvel of biological living systems. The regions of the earth close to the equator in north and south latitudes up to the transit of the sun, particularly in the neighbourhood of the oceans have the blessings of perennial rivers and other water resources. The peoples of these territories have access to extraordinary abundance of microbes, plants and animals. They meet with ease and certainty all their simple essential needs which provide them in turn the precious freedom and leisure for exploration, experimentation, speculation, creative expressions in new knowledge, languages, literature, performing arts, craftsmanship, with a variety of natural materials and tools. The leaders and rulers in these regions guided by the wisdom of empirical observations provided patronage and resources for the bold, and imaginative ventures in arts, culture, architecture and voyages to enhance sensory perceptions and appreciation as well as to create wealth and well-being of their peoples for meeting the needs of water, food, housing, clothing and ensuring health, nutrition, security, justice and much joy.

Rivers, deserts, forests, mountains, oceans had to be crossed for exploration. These necessitated evolution of engineering and technological capacities from scientific enquiries and laws of science. These were exchanged in trade and commerce and by aspirations for travel and quest. The richness and wealth of these regions in Southern Europe, Northern and Western Africa, West Asia, Coastal East Africa, Central Asia, South Asia, Asia Pacific and China have thus been the greatest originators of engineering and technology over five millennia.

These exchanges and interactions have increased substantially through greater facilities in seafaring and voyages across the Indian and Pacific oceans and the Atlantic. Thus transfer of new knowledge and materials between the Indian subcontinent, Pacific areas, China and Latin America also increased. The rich biological mineral resources and contact with the highly skilled personnel in India in design, fabrication, construction, navigation as well in complex manufacturing processes attracted attention of European powers. Thereafter interchange of economic plant materials became possible between Asia and Latin America. These regions constitute what is termed the Third World.

The great scientific advances in the past two centuries have resulted from novel engineering and technologies in energy generation and use in creation of industrial goods, services for improving health, nutrition and conquest of diseases. The Third World has gained power for self-rule and is aspiring to attain rapid economic growth and societal development. Indian developments in the past two hundred years and especially in the later half of the twentieth century have derived much inspiration and sustenance from interactions within the Third World.

Indian Enterprise

India has witnessed many developments in the past through contacts with South Asia, China, Japan, Korea, Mongolia, West Asia, Central Asia, Coastal Red Sea, Southern Europe and many countries of Africa. The languages, literature, architecture, cuisine, beverages, perfumery, textiles and garments, home implements, jewellery, paintings, crafts, musical instruments bear witness today of such engineering and technological exchanges.

As mentioned earlier, major initiatives in India by scientists and patrons of sciences have been aimed at creating capabilities and capacities for new technologies and applications for self-reliance to meet the needs and aspirations of the people. As elucidated in Section 2 India witnessed a renaissance in science and technology primarily through the vision and efforts of several dedicated brilliant scientists and their patrons. Before 1950, India had engineered production of sugar, textiles, chemicals from coal tar, pharmaceuticals, vaccines, dyes, industrial explosives and steel. Soon after Independence, guided by Jawaharlal Nehru, Mahalanobis and PMS Blackett, India launched programmes for engineering and technolgies for production of new drugs, antibiotics, machine tools, steel, non-ferrous metals, ships, aircraft and industrial control instruments. The nurturing of the Council of Scientific Industrial Research by S.S. Bhatnagar with active support from the Government formally encouraged technology generation for self-reliant economic development. These objectives are continuing to be realized by active partnership with Industry and basic sciences. Brief reviews of the primary engineering and technology generation leading to success are outlined, while taking note of the serious new concerns that have grown in the last three decades on global environment and loss of biodiversity.

> THE NURTURING OF THE COUNCIL OF SCIENTIFIC AND INDUSTRIAL RESEARCH BY S.S. BHATNAGAR WITH ACTIVE SUPPORT FROM THE GOVERNMENT FORMALLY ENCOURAGED TECHNOLOGY GENERATION FOR SELF-RELIANT ECONOMIC DEVELOPMENT.

India with a billion inhabitants perforce must promote and adopt numerous innovations in Engineering and Technology for achieving sustainable, development, recognizing the availability and limitations of its natural resources. The experience gained in meeting the needs of water, energy, food, health, housing and habitat, largely with self-generated and self- reliant technological advances in industry, services and human skills and for fulfilling aspirations in the next two decades are recorded.

Water Resources

Education and training in advanced civil and hydraulic engineering has lowered dependence on seasonal monsoon rains and melting of Himalayan snow for the rivers, through design and construction of big dams, canals and reservoirs. To a large extent floods have also been regulated. Through irrigation, arid, desert and saline lands have been greened. Remote sensing satellite technologies have been added to traditional technologies for locating ground water. New membrane technologies have enabled major chemical and petroleum industries in Chennai to flourish with only municipal waste water. Soil lining with polymer agro films of canals, storage tanks and ponds as well as cover of farm lands have curtailed seepage and evaporation losses. It is not uncommon in the fertile Punjab and Gangetic Plains to raise three crops a year from short duration varieties, benefiting from

perennial sunshine coupled with irrigation. Lined ponds have promoted fish farming on a large-scale. The desalination engineering of cooling tower discharges in petroleum, chemical and thermal electrical power generation by membrane and osmosis technology has led to fresh water conservation. Closed cycle fresh water circulation, cooled by once-through sea water in coastal region in industry is increasing. Rain water harvesting through appropriate indigeneous technologies is being introduced in many regions.

Brilliant hydraulic design engineers have, since Independence been responsible for building great dams and barrages all over the country. Rivers also are an important means of transport with bridges to facilitate their navigation. Dams and waterfalls provide hydropower. Abundance of such hydropower supported electrolytic hydrogen and alkali production. The potential for harnessing river and rain water resources is very high through appropriate new technologies. Development of small and micro hydropower equipment of high reliability is able to provide water and electrical energy to small isolated mountain communities. Such power is also stored in efficient batteries for night lighting and for hospital equipment, telecommunications, education and television in remote areas. Rural village communities in arid and semi arid zones in Western India have adopted new technologies for conservation of rain water to raise forests with fast-growing trees and shrubs for fodder, fire-wood and minor timber. Major advances in Ion exchange and membrane based technologies and highly reliable equipment have ensured safe drinking water supply at low cost in urban areas as well as in schools and hospitals. In the islands of Lakshadweep and Andaman and Nicobar and in coastal areas of Kerala, introduction of salt-tolerant varieties of crops such as rice, coconut, have been successfully employed.

The detection of presence of toxic arsenic in ground water in eastern India has prompted development to limit such sources for use by humans and livestock.

A special concern is related to water reservoir-induced seismic activity in high dams especially in the light of growing knowledge of plate tectonics on the movement of Indian Peninsular Plate against the Himalayan plate. Owing to deforestation in the catchment areas, there is a heavy loss of top soil and silting of the rivers causing flash floods and decrease in the storage capacity of the reserviors. Further, reduction in the depth of estuaries is leading to the lowering of the limits of tonnage of ocean liners in ports and harbours such as Haldia of the Ganga-Brahmaputra Delta and is receiving serious attention of engineers.

Global warming even on a miniscule level will increase the flow from melting snows of the Himalayan peaks and sea level rise in coastal regions affecting major urban centers and fishing communities. This is of special concern in the Indian subcontinent and has ushered substantial Indian scientific contributions for international studies.

Land Quality Management

The vast increase in agriculture during the fifty years has been possible through very large additions in irrigation, introduction of high-yielding varieties, use of fertilizers and pest and weed control measures. The gross irrigated land has increased from 25 to 70 million hectares. The net sown area of 142 million ha of all types cannot be further increased. The demand from urbanization, housing and industry is converting land to non-agricultural uses. There is an important need to augment the area under forests. Fresh land addition is possible only through reclamation of mined areas and unproductive lands severely affected by salinity, alkalinity and water logging. Reclamation through appropriate technologies using a consortium of microbes and plants are being developed in a few centres (see chapter on Plant Sciences) for generating forests. Engineering efforts to reclaim land from the oceans has been done for urban purposes in a few coastal areas. Other engineering and technological efforts are in progress.

Innovations in balanced use of synthetic and natural organic fertilizers, integrated pest management technologies and regulated utilization of ground water are methods being applied to ensure sustainable development. Cooperative efforts on wasteland treatments by accurate ground water surveys and computerized systems of modelling are being evolved.

The rural population of India increased from 300 million in the past fifty years to 630 million and may increase further to 700 million in a decade. With mechanization of agriculture, mining, transport and small-scale industries, employment opportunities are dwindling markedly and there is considerable migration of rural people to urban areas.

The Indian urban population has grown sharply from 50 million to 370 million in the last fifty years and may reach 465 million in 2020 with consequent demands for housing, transport, commerce, education and medicare. The planning for very large cities of 10 million and above in the decade requires innovations in engineering and technology and active cooperation with social scientists. Practical solutions are to be found to meet the needs of the migrants, maintenance of peace and of human dignity by gainful use of all citizens. Technologies are being developed for reduction of non renewable urban waste, positive use of solid waste and treated by new technologies are conserving land for sustainable development technologies for use of agro-domestic waste and carbonaceous materials for steam and power generation..

Energy

Five decades ago the country was blessed with abundance of forests. The major domestic energy needs were met from firewood and crop residues. The total amount of coal consumed was 30 million tonnes for power generation, industry, cement, brick and construction materials. The total annual consumption of petroleum products was one million tonnes, predominantly used by urban homes and municipalities. There has been an enormous increase in energy needs and use of non renewable sources. The future developmental goals are highly dependent on such energy. The quantum of these is discussed together with the engineering and technological innovations for ensuring high quality environment in land, water, ocean and atmosphere to meet international standards. The energy in India needs to grow at about eight per cent per annum for economic development with the yearly population increase of 1.7 per cent.

The ampleness of renewable resources at the time of Independence may be illustrated by the use of forest wood in Kerala for ammonia fertilizer technology and for methanol production. Even today about 50 per cent of total energy of the country is contributed by bio-mass. Hydropower was abundant five decades ago, when energy demand was not high. Hydropower is still an important source presently with a capacity of 23,000 MW. The major increases are from thermal power from coal and lignite. There is increasing demand for petroleum, oil and gas.

Technologies in Thermal Power Generation

The present installed capacity is about 100,000 MW out of which 70,000 MW are derived from coal and lignite, the balance is mainly from oil and gas sources. The addition in the next decade is likely to be 100,000 MW with 60 per cent from coal and lignite. The current annual generation is 500 billion watts. Coal in India is largely from mines in Bihar in the North and West Bengal areas. Transportation by rail to Western coastal India involves long rail transport involving energy consumption. Indian coal has also high ash content. Lignite is mined mostly in South India, Andhra Pradesh and Tamil Nadu and power generation is located close to extraction site. There are coal reserves deep underground in the State of Gujarat.

Major advances have been made in design of large size steam boilers and rotating machinery of

generators. There are efficient coal especially near mine sites where mega generation plants of capacities totalling 2000 MW had been developed. Engineering perfection has been achieved by Indian design and manufacture of all plant, machinery, electronic instruments and computer based operation controls for thermal power generation. The Plant Load Factor has been increased to 73 per cent.

Technologies developed relate to utilization of fly ash at a level of 10 per cent in cement and in the production of fly ash bricks and ceramic tiles and sanitary ware. The fly ash disposal continues to be a major concern and innovations in land filling and in mines are being attempted. Here again cooling tower water desalination and reuse are being practised. Emissions to atmosphere are controlled by treatments to reduce sulphur and nitrogen oxides to very small amounts.

Innovations in Technology

Major innovations are aimed at higher efficiency by operation to total design thermal capacities and reductions in atmospheric emissions. These are based on greater efficiency in steam generation as well as in the production of gaseous forms of fuel. Success has been achieved in pilot scale gasification and in continuous operation in small size power generation plants.

The technology of Fluidized Bed Combustion in boilers is a major step. The Integrated Gasification Combined Cycle (IGCC) Technology developed in India, produces a totally ash-free gas which is then utilized for higher inherent energy in the coal for conversion to electrical power with a consequent enhancement of power generated with the same coal from 27 to 32 per cent. Until now IGCC has been in use in a proven manner only with natural gas and not with coal. The higher capital costs are justified by increased amount of power generated from given quantity of high ash coal and total absence of particulate emmissions. Electrostatic precipitators in the present power plants have also reduced substantial amounts of particulate matter emission.

An outstanding technology has been the pilot scale demonstration of in situ deep underground coal gasification to make available gas fuel for power generation without the need to mine and lift such coal to ground level. This technology would be very valuable in the future and needs to be fully supported.

The present peak load capacity utilization in thermal Power is 95,000 MW. The energy generation increase from about 200 MW, 50 years ago is a clear indicator of economic progress. Further additions in the next seven years would be 1,70,000 MW capacity in thermal power.

Petroleum Oil and Gas Technologies

Petroleum Oil and Gas have become the dominant materials in the world during the last 50 years for the extraordinary economic growth of the Western World of Europe and North America. The discovery of oil and gas in West Asia, North Africa, Middle East and the Gulf Countries was made 25 years ago. Additional sources of oil and gas have been located in North Sea in Russia, Central and South East Asia, Bangladesh, China and in Central and South America. Petroleum and gas have become the key materials for energy for industry and infrastructure and for chemicals, fertilizers, petrochemicals, metals, new novel materials. The realization of their value to the world economy has led to generation of great wealth for several Developing Countries. Coal which served as the major source for the industrial revolution for steam, electricity has been replaced and nuclear energy growth has slowed. Coal tar, a by product in the production of coke for steel manufacture as well as alcohol from molasses in sugar making which were the major sources for chemicals, plastics and fibres have been displaced by petroleum oil and gas. Vast increases in air, ocean and land vehicle transport have resulted from increased availability of petroleum.

Major international investments have been in

research, new technology development and adoption of the technology. These new technologies are constantly adding to the creation of wealth and prosperity of the world in a manner unsurpassed in human civilization at a time of enormous increase in population. The great advances in chemical sciences and technologies of the eighteenth and nineteenth centuries and the first half of the twentieth century have been the major factors. In addition, advances in physics, spectroscopy, crystallography and electronics have created techniques and scientific instruments of extraordinary sensitivity to comprehend the complexities of chemical transformations. Geological and geophysical technologies for exploration have led to new reserves. New alloys and novel new materials are crucial in the fabrication of very large equipment for production and safe transport of oil and gas and manufacture of petroleum products and petrochemicals without corrosion and failure.

India has been able to make large strides in research and largely self- reliant technology and engineering in this sector. Oil was discovered in Assam in 1875 in a location named Digboi. Oil and gas recovery and a small refinery were established in 1933 by Assam Oil Company and these have continued to function till now. Recognizing the importance and complexity of petroleum products major international oil companies have established refineries in Mumbai, Kochi (Cochin), Chennai and Vishakapatnam. The Government of India promoted the Oil and Natural Gas Commission in 1956 and the efforts of geologists led to the discovery of oil and gas onshore in Gujarat and later in Mumbai offshore and gas fields in Northeast India . As in other sectors, Government invested in Petroleum processing and construction of Refineries in Vadodara, Barauni, Haldia with assistance from Russia and East Europe. The Indian Institute of Petroleum to carry out research and a consultancy organization Engineers India Ltd for project engineering were instituted during 1962-66. The ownership of international oil companies was transferred to the Government in 1975 soon after the major international discoveries of oil and gas and also in western India and offshore. These have led to major contributions in India in research, technologies and expansion of the oil sector and its continuation. For the first time in India, the entire detailed design, detailed engineering of equipment, civil structures, utilities, stage-wise inspection of fabrication, erection and commissioning of processing petroleum, oil gas and petrochemicals, polymers could be carried out successfully from 1975 by Indian organizations. Several thousands of engineers and technologists and others have been trained in many skills in such a highly complex venture. Research in many institutions has led to new processes, catalysts and separation technologies. They have contributed to self-reliant development in public and private sector in India and have led to major project assignments abroad. For over two decades the Oil Industry Development Board and the Centre for High Technology supported by the Ministry of Petroleum and Natural Gas. have pioneered the development of several new technologies. All the organizations involved in exploration, onshore offshore production pipeline transport, refining to high value added products as well as formulations of lubricants are meeting environmental standards. These companies and Design and Project Engineering organizations have developed high quality R&D Centres and special units for safety. These are unique to the Oil and Gas sector and have been the basis for unsurpassed success in the past 25 years and for equipping it to enter World Free Trade and Patent regime shortly.

Indian requirements of petroleum products have increased from one million in 1950 to 100 million tonnes currently. Imports are 75 million tonnes, of crude per annum and will increase to 177 million tonnes in six years using Indian technologies and Indian equipment. Large increases in petroleum refining capacity have been made in

the last 20 years. The total basic and detailed engineering, equipment selection, installation and commissioning and operation capacities have been developed in these two decades. Virtually fabrication in India of all items of complex special steel equipment, including major facilities for storage in spheres of liquefied gases at low temperatures of -170° C has become possible.

Indian organizations have successfully completed major projects on LPG, LNG and Refinery in Algeria, Abu Dabi, Iran, Iraq, Libya and have made contributions in Malaysia and Vietnam. Excellent coordinated efforts between universities, research laboratories of CSIR have resulted in generation, production and large-scale use of new catalysts, molecular sieves and technologies for meeting high environmental standards. The Refinery at Mathura, 60 km from Agra City is one of the three in the world to be recognized for meeting the ISO 14000 standard. The internal energy consumption in processing in refineries has improved from 9 to 3 per cent.

The quality of diesel has been greatly improved. Sulphur content has been drastically reduced in Indian refineries initially to 0.25 per cent. In the near future, enhanced hydro desulphurisation technology would lead to very low levels of emission from automobile transport and power generation to the atmosphere. The aromatics content of diesel in naphtha and petrol has also been reduced to eliminate benzene.

Capabilities for exploration, offshore production of crude oil and gas, design, fabrication and installation of offshore facilities are now well-developed as also for sub-sea pipeline transport. Total technology and engineering has been accomplished for LPG production two decades ago. Major technologies have resulted in high recovery of distillation products, gases for petrochemicals, polymers, microcrystalline wax and high value products. India has outlined a Vision for 2025 for the Oil Sector and has committed for free trade in petroleum products from 2002. Engineering and technology as well as skilled human resources have created confidence for international competitiveness.

Crude production in Western onshore and offshore and to a small extent in the North East is declining from a peak of 35 to 26 million tonnes. Exploration has been intensified. India will be a major importer of Oil and Natural Gas from several countries, including those in the Third World. There are very high potentials for cooperation in engineering and technology to meet ideals of conservation, environmental quality and innovation.

Nuclear Energy Technologies

The self reliant advances in technology for generation of Nuclear Power have been mentioned elsewhere. The remarkable achievements are in design, fabrication, installation of equipment, production of high quality fuel materials such as Uranium 238 from Indian uranium ore sources, heavy water from ammonia fertilizer plants, especially using hydrogen sulphide utilized in the indigenously designed power reactors. Technology is being generated for large future investment in Fast Breeder Reactors, based on thorium from abundantly available Indian ores. The current Nuclear Power Generation capacity of 2720 MW is expected to double shortly. Nuclear Power will continue to be an important source of energy in the country.

Electrical Power Transmission Distribution Technologies

India is a country of vast distances with coal resources confined to one area. Transmission losses in electricity in the present technology are estimated at 15 per cent. A technology for more efficient transmission has been developed and demonstrated in High Voltage Direct Current (HVDC) in place of relatively Low Voltage Alternate Current for long distance. This innovation is of great significance in plans to evolve an efficient management through Regional Grids and eventually a National Grid.

Technologies for Power from Renewable Sources

The technological advances from renewable sources are to be found in this volume in Chapters on the Ministry of Non-Conventional Energy Sources, Department of Biotechnology and Department of Ocean Development.

Technologies for Solar power with Indian Amorphous Silicon Panels, as also from Indian Wind Farms have been demonstrated. An attempt to use ocean wave energy has been made. Proposals for ocean thermal energy conversion are under consideration. Community biogas generation from rural wastes from livestock has been demonstrated. In the early years, biogas generation was found to be low during winter months in north India. New genetically engineered microorganisms for higher efficiency in conversion capacity to perform at low temperatures with assurance of year-round generation are yet to be evolved.

Metals and New Materials

Technological advances in steel have led to production of high strength alloy steels. Copper, zinc and lead are produced efficiently in the country. India has very high reservoirs of Iron ore and bauxite. The country is a major producer of aluminium and has also developed technologies for the high strength special aluminium alloys essential for aircraft. Indian bauxite and aluminium production are in a position to yield a large amount of the very valuable metallic element gallium. Technology for high quality gallium has been evolved on a pilot-scale and can be readily adapted for large-scale. Gallium arsenide has considerable potential in the electronics and related industries.

There is wide special knowledge and new technology available for the development and production of numerous catalysts using nickel, cobalt, palladium, selenium, silicon, ruthenium, copper, rare earths for applications in the oil, gas, chemicals, fertilizers, drugs, polymers and fibre industries. There are also excellent technologies for fuel cell power and high efficiency power storage batteries, photovoltaics and devices for controlling automobile exhaust emissions. These arise from basic knowledge in metallurgical science, microanalysis spectroscopy, crystallography, solid state chemistry and condensed matter physics. Many major advances in energy conversion, storage, controlled usage are in need of such knowledge as also photography and communications.

There have been notable achievements in the production of liquid crystals carbon fibre, composites, engineering polymers, optical glass, amorphous silicon photovoltaics, special starches, modified celluloses, membranes, special absorbents and gelling agents.

Communications Technologicals

The vastness of the country with a billion people, using over a hundred languages and other dialects, fifteen officially recognized written languages, pose many technological challenges in communication. Great success has already been achieved in telecommunications, television, satellite development, orbit placement and usage. The educational system has expanded vastly with common syllabi, qualifying examinations. The democratic system, the legal and justice administration rely on transparent and rapid communication, computerized storage and retrieval with simultaneous automated translation. The Union of India with its parliamentary system and constitution has succeeded immeasurably among the newly Independent countries in the developing World.

The Indira Gandhi National Open University with nation wide higher education network is an outstanding testimony to the success of the communication technology.

The role of the communication system in the documentation of the enormous cultural creativity in rural and local handicrafts, mutitude of technologies in handloom, dyeing, metal forming, casting, pottery, ceramics, moulding as well as in

several thousands of celebrations of festivals, music, dance, performing arts has been invaluable. These have encouraged tourism, trade, commerce, horticulture and cooking. India is the country with the world's largest growth in telecommunications, technologies, devices and for innovations yet to emerge.

Technologies for International Trade

India has had a long tradition of multifarious designs and preparation of textiles and garments by hand craft in different parts, using local raw materials such as cotton, jute, wool, linen and other plant materials and silk. The extraction of pigments and fibres, spinning, weaving, dyeing and printing techniques were innumerable and characteristic of the subregion. They were important in preserving individuality and excellence. Special textiles and garments were made for celebration of festivals, birth and marriage ceremonies, dances, performing arts and as offerings. Looms have many variations and designs and are run by notations based on complex mathematics and engineering technologies. In some instances the making of a garment or *saree* and weaving of carpet takes a few months. Specially light wool fabrics are woven from the under-fur of goats such as angora and pashmina native to the mountain peaks of the Himalaya. These are highly valued internationally and fetch high prices. The importance of these native for the economy of each rural center was long recognized and Mahatma Gandhi symbolized the spinning wheel for handmade cotton yarn *khadi* and the homespun cloth *khaddar*. The related products of ceramics, pottery, bamboo and cane wickerwork and of incence, honey, flavours, perfumes, bronze, stone, marble objects, musical instruments have become the core of khadi and village Industries. The crafts tradition is a vital force. The first President of India, Rajendra Prasad was drawn to the Freedom Movement by the plight of the farmers in Champaran, Bihar, who were producing the plant derived dye Indigo by competition from low-priced imports of synthetic coal-tar based dyes from Europe. Laksha from the lac insect (laccaic acid) and alizarin obtained from madder root are valued reddish dyes. The chemistry of natural colouring matters has engaged the attention of numerous renowned scientists of Europe and several Indian scientists notably T R Seshadri and K .Venkataraman. There is now a worldwide demand for textiles prepared with natural dyes and total absence of synthetics. Modern technology is being incorporated into the rural Centres to increase productivity, reduce arduous labour and to enlarge the range of products in demand. The National Institute of Design, Ahmedabad has pioneered new designs and has trained highly qualified engineers to provide assistance to the weavers and other artisans.

Items such as handcrafted jewellery made of precious and semi-precious stones in myriad traditional designs, ethnic jewellery made of anodized silver and other metals, bangles made of bone, ivory, wood and glass offer a wide range to tourists and markets abroad.

Likewise access to a primary need, namely salt was also chosen symbolically by Mahatma Gandhi for ensuring the right to make salt for essential family use. Another basic material in village economy, skins and hides from the vast animal population were prepared by a particular section of the rural community. Mahtma Gandhi elevated them to be valued members of the society. Processsing of raw hides to leather and leather goods using vegetable tannin materials is an ancient technology. Leather products are in high demand for local use and export. The application of innovative science and technology by the Central Leather Research Institute (CLRI), Chennai have eliminated virtually all toxic and environmentally unacceptable chromium from effluents. Nayudamma and his successors at CLRI has played a crucial role in leather industry with excellent design, footwear, bags and leather goods form major export items from India.

The import of cotton fibre and textiles from Europe invited opposition of the Indian Cotton

Mills who also became major patrons of self reliant development and supported Indian research widely. The cotton industry pioneerd the production of industrial starch and expanded it for .preparation of glucose and industrial enzymes in Ahmedabad and Coimbatore in South. The expertise and valuable experience gained promoted investment in fermentation technology for antibiotics and drugs. Similarly, the Indian cotton mills industry made investments in rayon and later to nylon, polyester, acrylic fibres.

Other major rural agricultural and forest products have been significantly improved through food technology initially for preservation at low cost and increasingly to manufacture highly value added products in food, spices, tea, coffee, cocoa, flavour and perfume concentrates, wines, medicinal products and pharmaceuticals. The large investments for economically profitable products involve high technology including super critical carbon dioxide extraction in maintaining quality, improving the genetic varieties of sources of raw materials and ensuring supply for sustained manufacture for Indian markets and export.

Engineering and Technological Capability

Independent India, valuing the need for economic development soon after Independence arranged to send in 1946 and 1947, 600 engineers and scientists to Europe and North America for periods varying from 2-3 years to be specially trained in chosen fields of engineering and technology. The fields included coal, mining , metallurgy, chemical, engineering, instruments, machine tools, foods, fermentation, glass, ceramics, textiles, leather, reservoir engineering. building and road construction technology, cement, aeronautics, ports, harbours and naval architecture. These persons returned to India and became pioneers of many new technological research institutions. The foundation of Industrial research institutions with government support in partnership to industry was another major step. The process was extended to Electronics, Electrochemicals, Scientific Instruments and Petroleum. Biotechnology, Molecular Biology and Microbial Technology have been added in recent year.

The Government of India has also supported the growth of technological services in Indian standrads and engineering Design and project Consultancy. These are now available for innovative areas such as software, testing for quality, Medical diagnostics. The Consultancy Development Centre with several hundred consultancy organizations has generated opportunities worldwide for services in health, medicare, technological education, environment as well as in international financial development institutions and United Nations Organizations. Technological capabilities developed in the government-owned industry and other institutions form the base for the new non-Government ventures in India and internationally in the new era of knowledge based on economic development

Engineering and Technology for sustainable development of the World and especially the Third World is fundamental for the advancement of human civilization with harmony and peace while preserving the diversity of cultures.

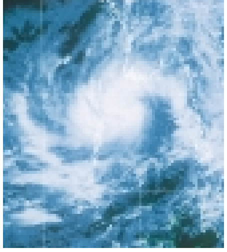
The Golden Jubilee of your Academy comes within a year of the Silver Jubilee of the Scientific Policy Resolution. I should like the Academy to examine to what extent science and technology in India have been decisive agents of dynamic and beneficial change. Every institution must renew itself and be constantly thinking of its work in the future. Members of the Academy, so much more than others, are in a position to understand the implications of the development in science, to educate public opinion and to advise Government.

- Indira Gandhi
From her inaugural address to the
Golden Jubilee Celebrations of the Academy, 1984



IN SERVICE OF THE NATION

Science and technology are driving forces of development. In most countries specially in the developing ones the Government provides the major support to meet the social needs. Over the years successive governments in India have created new science departments, agencies and commissions to fulfill this obligation. An outline of their objectives evolution and achievements are reflected in this section.



CHAPTER XXV

COUNCIL OF SCIENTIFIC AND INDUSTRIAL RESEARCH

The Council of Scientific and Industrial Research (CSIR) is the name of the nation-wide research platform consisting of a network of laboratories which spans the geographical dimensions of India. Its programmes which bridge various disciplines, address specific needs which arose in the process of social transformation in the post-colonial context and demands which our society faces in this period of globalization.

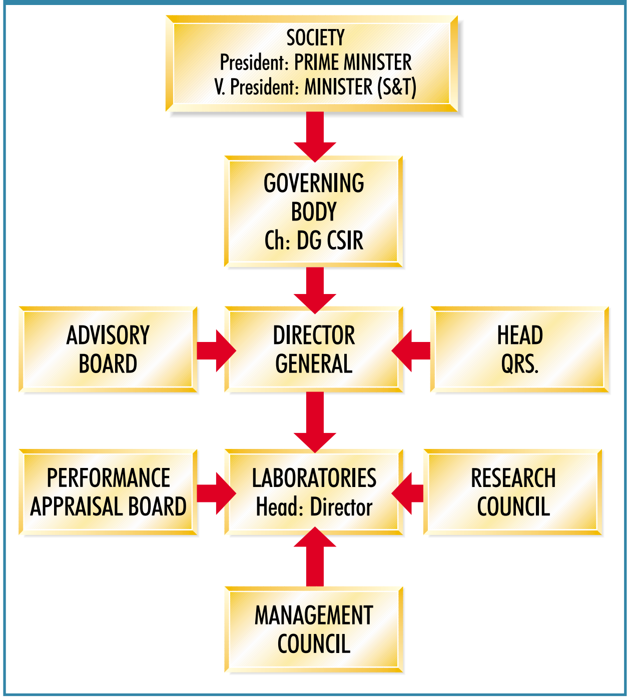
This multidisciplinary and multilocational council runs 39 laboratories and 80 field centres which carry out fundamental and applied R&D in all areas of science and technology, barring atomic energy. The dynamic dimension of the network is the pool of knowledge and expertise of over 5000 active scientists of repute, supported by over 10,000 scientific and technical personnel. This scientific infrastructure was built up over six decades at a cost of equivalent to 1 billion US dollars at current value.

The foresight of its founding vision has been vindicated by CSIR's capability to serve not only as a national R&D infrastructure but also a platform for international collaboration and research projects, thanks to its interlaboratory and interdisciplinary experience. It now works on an annual budget of around $250 million.

The CSIR was established in 1942 as a autonomous, non-profit organization with a wide ranging charter of functions. These included promotion, guidance and co-ordination of scientific and industrial research, collection and dissemination of information on research and industry, founding of laboratories to carry forward scientific and industrial research and utilization of the new knowledge so generated for development of industry. CSIR was also charged with other tasks such as rendering assistance to other institutions conducting research, awarding of fellowships and publishing of scientific journals.

As a springboard for scientific and technological activity, CSIR helped usher India into

CSIR ORGANISATIONAL STRUCTURE



CSIR INDIA NETWORK OF R & D LABORATORIES



PHYSICAL SCIENCES

1. Central Electronics Engineering Research, Institute, Pilani
2. Central Scientific Instruments Organisation, Chandigarh
3. National Geophysical Research Institute, Hyderabad
4. National Institute of Oceanography, Goa
5. National Physical Laboratory, New Delhi

CHEMICAL SCIENCES

6. Central Electrochemical Research Institute, Karaikudi
7. Central Leather Research Institute, Chennai
8. Central Salt & Marine Chemical Research Institute, Bhavnagar
9. Indian Institute of Chemical Technology, Hyderabad
10. Indian Institute of Petroleum, Deharadun
11. Regional Research Laboratory, Jorhat
12. National Chemical Laboratory, Pune

BIOLOGICAL SCIENCES

13. Central Drug Research Institute, Lucknow
14. Central Food Technological Research Institute, Mysore
15. Central Institute for Medicinal and Aromatic Plants, Lucknow
16. Centre for Biochemical Technology, New Delhi
17. Centre for Cellular & Molecular Biology, Hyderabad
18. National Botanical Research Institute, Lucknow
19. Indian Institute of Chemical Biology, Kolkata
20. Industrial Toxicology Ressearch Centre, Lucknow
21 Institute of Microbial Technology, Chandigarh
22. Regional Research laboratory, Jammu
23. Institute of Himalayan Bioresource Technology, Palampur

ENGINEERING SCIENCES

24. Central Building Research Institute, Roorkee
25. Central Fuel Research Institute, Dhanbad
26. Central Glass & Ceramic Research Institutue, Kolkata
27. Central Mining Research Institute, Dhanbad
28. Central Road Research Institute, New Delhi
29. National Aerospace Laboratories, Bangalore
30. National Metallurgical Laboratory, Jamshedpur
31. National Environment al Engineering Research Institute, Nagpur
32. Regional Research Laboratory, Thiruvanathapuram
33. Regional Research Laboratory, Bhopal
34. Regional Research Laboratory, Bhubaneshwar
35. Structural Engineering, Research Centre, Chennai
36. Central Mechanical Engineering Research Institute, Durgapur

INFORMATION SCIENCES

37. National Institute of Science, Technology and Development Studies, New Delhi
38. Indian National Scientific Documentation Centre, New Delhi
39. National Institute of Science Communication, New Delhi

SCHEMATIC DIAGRAM NOT TO SCALE

a scientific milieu, creating and nurturing talent in science, innovation and technology. It spawned many organizations, many disciplines and most importantly has served as a nursery and training ground for India's talented scientists and technologists.

On one hand, CSIR has assisted industry in the development of viable and globally competitive technologies and on the other, has provided back-up support in exploration and exploitation of indigenous raw materials and natural resources for import substitution, pollution control and effluent treatment, waste utilization and energy conservation. CSIR's inherent strength lies in its ability to form special interdisciplinary, inter-laboratory, international groups to tackle specific research and development problems. To cite one example, a consortium of 20 CSIR laboratories, 10 universities and three organizations dealing with traditional systems of medicines, is working in a 'Team India' initiative to synergies high science with traditional wisdom and India's rich biodiversity to discover and develop bioactives from plant sources. In yet another endeavour, CSIR laboratories have teamed up with academia, steel industry and government to develop mathematical models to stimulate steel production in a blast furnace. There are many more other similar alliances.

A Proud Record

CSIR has several radical scientific achievements to its credit, such as: the induction of precocious flowering in plantlets of bamboo raised in tissue-culture, discovery of one of the (then) smallest protein molecules, seminal plasmin; the first formulation of a model of crack-tip energy dissipation; the first combined genetic and physical map of the whole *V. cholerae* genome; the development of a salt sensitive expression vector, used successfully to clone and express six divergent genes; the elucidation of the mechanisms for delaying the formation of cataract in the human eye; the first study to give an understanding of the outer ionosphere and may others.

CSIR

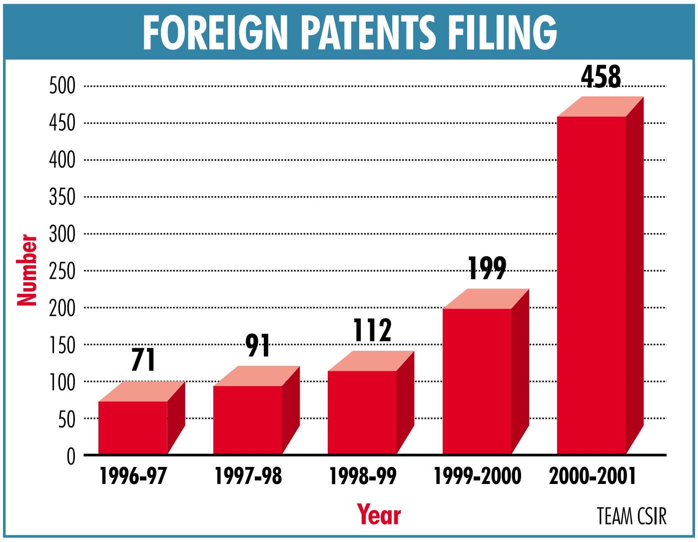
- A 59 year young, not-for-profit R&D organization
- Prime Minister of India as President
- 39 laboratories, 80 outreach centers, spread nation-wide
- 22,000 strong work force
- 5000 Scientists/technologists
- 2,500 Doctorates

CSIR's R&D Services:

- Aerospace & Aeronautics
- Bio-sciences & Bio-technology
- Chemicals & Chemical Technology
- Coal, Gas and Petroleum
- Construction Technology
- Drugs & Pharmaceuticals
- Earth & Ocean Resources
- Ecology & Environment
- Electronics & Instrumentation
- Food Processing
- Leather & Leather Goods
- Machinery & Equipment
- New Materials
- Mining & Metallurgy

- Value of R&D infrastructure over USD 1 billion
- Annual Budget USD 250 million
- Over 1000 CSIR technologies commercially exploited
- USD 1 billion worth of industrial production per year
- 2000 scientific papers published per year
- 500 Indian & 650 foreign patents filed per year
- Bilateral Scientific Collaboration with 30 Organizations in 27 countries

On the technology front, CSIR performance is equally impressive. CSIR announced an intellectual Property Policy in 1995 and has gone on to file annually around 500 patents in India and around 650 patents abroad, the numbers being higher than those of any single Indian organization. Over the years it



has developed more than 3,000 technologies and licensed 1,500 of them to about 6,000 clients. The annual industrial production based on CSIR techniques and technologies is estimated over $1 billion. Its S&T services and inputs annually generate productivity savings of around $500 million.

CSIR was the first to introduce buffalo milk for baby food (brand name 'Amul'); it launched the wholly indigenous tractor *Swaraj*; developed a cost-effective process for drugs for mass use; it initiated the design of building foundations suitable for black cotton soil; it was the first to extract polymetallic nodules from the Indian ocean bed, based on which India became the first country in the world to be granted 'Pioneer Status', under the UN treaty on the Law of Seas; it built an all-composite small aircraft, *Hansa*. Significant S&T activities and achievements are spread across a wide range of areas.

Aerospace S&T: The National Aerospace Laboratories (NAL), Bangalore, of the CSIR is a major player in India's aerospace programmes. It has developed world class capacity for design, development and fabrication of large components of advanced composites for civilian and combat aircraft, structural testing and analysis, aerospace electronics and systems, innovative capabilities in surface engineering etc. The activities are focussed on design, development, fabrication and airworthiness testing of small civilian aircraft and on creating, maintaining and providing high class expertise and world class test and certification facilities, such as National Trisonic Acoustic Facilities, Aerodynamics Test Facilities, Full-scale Fatigue Test facility, FRP and composites pilot plant facility. NAL is now spearheading the initiative to create a civilian aircraft industry in the country. It has already developed, designed, fabricated a two-seater trainer aircraft, *Hansa*-3, which has been certified for day and night flying. It is now engaged in the design, fabrication and airworthiness testing of a 9 to14 seater multipurpose light transport aircraft.





Left: Saras, 14-seater light transport aircraft. Right: Two-seater trainer aircraft Hansa-3, which has been certified for day and night flying.

DEVELOPMENT OF DRUGS BY CSIR LABORATORIES

The major players are CDRI Lucknow, IICT Hyderabad, NCL Pune and RRL Jammu.

Responsible for developing and licensing 12 new drugs to the industry.

Developed and transferred technology for over 100 drugs and intermediates. About 30 major drugs and a dozen intermediates being currently produced with CSIR developed technology.

Services offered include consultancy, contract and collaborative research, assimilation and modification of imported technology, training and data search and analysis.

Providing help and consultancy to international agencies like UNIDO, UNCTAD, WHO.

Biology and Biotechnology: CSIR's contributions in this area have been wide ranging including genomics, control of gene expressions, recombinant DNA products, to molecular and cellular biology, tissue culture, agrobiotechnology and fermentation. It had the distinction of placing India among the first few nations to develop its own multi-locus, BKm derived probe for DNA fingerprinting. Pioneering work has also been done on leishmania, cholera, cataract formation in the eye, apoptosis, and antibacterial properties of plant material. It has also developed several PCR based markers and diagnostic systems.

The development of elite genotypes of *Mentha arvensis* has enabled India to contribute mentha-*menthol* to the world as the leading producer of this product, along with the development of many novel and improved strains for several medicinal, aromatic and flowering plants.

CHEMICAL SCIENCES AND TECHNOLOGY

The area of chemical science and technology is the one in which CSIR's work has enjoyed high visibility, consequently bringing along credibility with the chemical industry, in areas of agrochemicals, drugs and pharmaceuticals, petroleum and petrochemicals, catalysts, and chemical intermediates, subsectors that call for a high level of innovativeness.

Over 30 new and cost-effective agrochemical processes have been developed for the production of a whole range of organophosphorous pesticides. Later, the focus was turned on the development of pheromones and biopesticides. In the area of drugs and pharmaceuticals, the country felt the need for cost-effective and commercially viable technologies for a wide range of essential drugs. The development, consequently, of such drugs as for example anti-cancer, anti-virals, anti-bacterials, anti-glaucoma, anti-inflammatory, analgesics, and cardio-vascular drugs among others, gave the much needed fillip to a nascent Indian drug industry to emerge as the largest producer of generic drugs in the world. At the same time CSIR had the distinction of bringing 12 entirely new drugs into the market.

Catalysts: CSIR Success Story

1970s	Learning: Import substitution DMA, Vanadium Pentaoxide, Raney Nickel
1980s	Catching-up: Improved catalysts bimetallic for reforming, nickel Alumina for hydrogenation, iron oxide for dehydrogenation
1990s	Global emergence: Improved & new catalysts : formaldehyde, methylethyl Ketone, Xylene isomerization
2000	Global stature: Novel catalysts & processes: Linear alkyl benzene, adipic acid, biphasic catalysts, methane to higher hydrocarbons.

India is among the top five countries that possess world class capabilities for development and manufacture of new catalyst formulations. Starting from developing known catalysts, CSIR introduced its own brand of new zeolite catalysts, named 'encilites', for diverse industrial processes. It introduced the novel concept of promoting interfacial catalysis in a biphasic system for the

Petroleum Process: Commercially Adopted

Product	Technology Partners	Commercial Usage
Benzene & Toluene Extraction	CSIR, EIL	BPCL, CRL
Xylene Isomerisation	CSIR, IMCL, EIL	IPCL
Food grade Hexane	CSIR, EIL	BPCL, MRL
Toluene Disproportionation	CSIR, IPCL, EIL	IPCL
Sulpholane	CSIR	CADILA
Hot Rolling Oil	CSIR, SAIL	LUBRIZOL INDIA
Lobs using NMP Extraction	CSIR	IOC
Bimetallic Reforming Catalyst	CSIR, IPCL	IPCL, MRL
Visbreaking	CSIR, EIL/S&W	IOC
Delayed coker	CSIR, EIL	IOC

hydroformylation of several olefins using a rhodium complex. Efforts in this science based sector have yielded fruits and India now exports catalysts to the world including the western markets.

In the area of petroleum processing, a near-cartel situation on technology has been prevailing worldwide. CSIR, in association with its partners, has helped to break the stranglehold, having successfully developed processes that are now commercially adopted by several Indian refineries and grass-root plants.

Significant contributions in the chemical sector have also been made in the area of chemical intermediates. Process technologies were developed and utilised by industry for benzyl chemicals, glyoxal, sodium azide cyanuric chloride, hyderazine hydrate, phosgene, CFC substitutes etc. World class capabilities and facilities exist in the country today to provide for hazard evaluation, risk analysis, safety management, mathematical modelling and simulation.

Coal: In the early years CSIR helped in the setting up of all the coal washeries in the country and defined the washability index of coals for the first time. Since then, work has continued on developing new approaches to coal fines beneficiation and recovery from the washeries, design of mini-flotation plants etc. It has helped the steel industry to decide on coke blends; the power industry to evolve washing strategies and, most importantly, it has enabled the myriad small and medium sized beehive coke units in the coal belt of India to produce coke efficiently, with minimum pollution from inferior coals. There have been a pioneering endeavours in the developmental process in coal gasification and conversion of coal to liquid fuels.

Electronics: The electronics industry in the country has benefited largely from professionally developed specialized products. These include electronic systems for excitation control for the sugar and paper industries, diesel electric locomotives, AC drives for mining locomotives, three phase to single phase thyristor convertors, and a host of special purpose analytical and field instruments. CSIR is the repository of high-tech knowledge in microwave and travelling wave tubes and in klystrons and magnetrons. The capabilities in semiconductors created in its labs have provided tailor-make hybrid microcircuits for the Indian space programme and for other applications.

Food: In the area of food and food processing, several novel cost-effective and easy-to-operate techniques and processes have been developed by its laboratories in India. These cover the storage, conservation and processing of foodgrains, as also technologies for low-cost nutritious foods, food preservation, 'convenience foods' and non-conventional foods. S&T inputs have also gone into spices and spice products, grain-based foods of both the convenience and the speciality kinds, into the preservation, packaging and transportation of fruits and vegetables. Attention has been paid to develop appropriate and improved designs for machinery, such as those for milling for grains and pulses and other for food-packaging.

Housing and Construction: Modern techniques and technologies have been carefully developed to cover the whole gamut of construction activities, right from laying of foundations to fashioning of required construction equipment. CSIR designs for foundation for piles – under-reamed, bored, compaction, skirted, spliced -- are variously aimed to enable sound construction on varying types of soils encountered in the country. Newer and innovative building components developed have greatly helped the building industry to standardize optimal structural elements, such as RCC channel unit, RC ribbed slabs for floors and tiles, pre-cast stone concrete blocks, prefabricated brick panels. Alternative materials which have come out of sustained R&D work utilize waste, economise on energy and are eco-friendly. These products include fly ash bricks, sand lime bricks, red mud bricks, tiles from ferrochrome wastes, gypsum plaster boards, glass reinforced gypsum as wood substitute, corrugated roofing sheets from coir or wood-wool and ferrocement. In the area of structural engineering, CSIR laboratories have specialized in making design and analysis of special and complex structures such as highrise, longspan, suspended, offshore structures and of ships, and in the integrity assessment of these structures. The roads sector has also benefited from designs and constructions techniques, especially those honed for using local skills and materials.

CSIR's Contribution to Industrial Development

Drugs & Pharmaceuticals	Pioneered effective processes & new drugs development for self.
Pesticides	Catalysed domestic industry
Leather	Propelled industry for value addition, modernization and environment conciousness.
Petroleum & Petrochemicals	Novel processes for techno logical self-reliance & global positioning
Food Processing	Appropriate techniques & technologies for conservation & productivity
Building Materials	Utilization of wastes and endogenous resources
Economic Plants	Introduced & popularized new high value varieties of medicinal and aromatic plants.

Leather: The Central Leather Research Institute (CLRI) of CSIR is the largest leather institute in the world. Its S&T inputs and extension activities have been actively transforming the traditional leather industry into a modern, vibrant and environmentally responsive one. Pioneering contributions have been made at every stage of the industry's activity -- starting from techniques for the flaying of dead animals and the storage of skins, using either no salt or very minimum, going on to appropriate time-saving and low-pollution tanning and processing techniques using 'low chrome' and 'no chrome' tanning chemicals, to modernization of the net operations in tanning through computer application and subsequently proceeding to develop new techniques for generating value added speciality leathers, computer-aided designs for footwear, garments, and goods, fashion colour forecasting, export certification and, not the least of all, in creating both the human resources as well as the R&D that the leather industry and the sector needs. A pioneering Leather Technology Mission has been mounted for the sustainable development of the Indian leather industry which aims at vast grass-roots coverage.

Materials: From time to time, demand for special materials has arisen from sectors like aerospace, defence or sophisticated industries for developing such materials. Among them are: Electronic materials such as amorphous and polycrystalline silicon, ferrites, gallium, luminescent phosphors for display, piezoelectrolytics, high-purity alumina, conducting polymers and silver pastes;

- Aerospace materials such as high-density carbon-carbon composites, Nalar--a Kevlar equivalent high strength fibre, aluminium-lithium alloys, high purity aluminium;
- Industrial materials for special performance such as silicon carbide, silicon nitride bonded silicon

carbide, silicon carbide whiskers, aluminium-metal matrix and aluminium-graphite composites, special glasses for optical fibres, infrared range finders, laser glasses, radiation shielding glasses and sol-gel techniques for glass coatings etc.;
- Superconducting materials.

Metals and Metallurgy: In the metals and metallurgy sector, technologies developed by CSIR have been utilized to establish the first plants in India for magnesium, chromium, carbon free ferro-alloys, ferro-vanadium, zirconium and titanium powders and titanium electrodes. Besides it has developed novel processes for the direct reduction of iron ore to sponge iron for mini steel plants, and the technology for the processing of polymetallic sea nodules for recovery of valuable metals; gasfired cupola for use in cast iron foundries and high grade synthetic rutile.

Minerals: CSIR has contributed in a large measure for exploitation of low grade and inferior ores by devising flowsheets for copper concentrators, manganese pan sintering, iron ore washing and sintering, low grade fluorspar and graphite beneficiation, recovery of molybdenum, nickel and copper, beneficiation of low grade chromite ores, graphite etc. More significantly, it has recently set-up a technology demonstration plant for recovery of nickel from low assay chromite overburden.

Mining: CSIR has made significant contributions to all aspects of mining operations, especially in coal mines (to the exclusion of only heavy mining equipment). Studies and efforts on subsidence prediction and control have enabled the extraction of coal locked up in pillars and underneath surface structures and water bodies. CSIR has been the principal agent for designing appropriate mine ventilation systems and is now the main resource for mine disaster management in the country. It has devised appropriate roof support structures for bolting and stitching such as, hydraulic and screw props, safari clamps, triangular chock, etc. which are now being manufactured by scores of small scale units in the mining region of Bihar. It is responsible for testing and certifying the safety equipment for miners' personal and flame proof quality of electrical equipment etc.

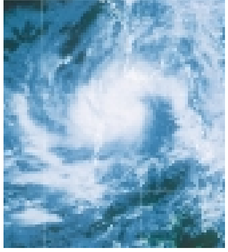
Ecology and Environment: When S&T inputs are needed to evolve national policies and to ameliorate environmental problems, CSIR is a major contributor. It has developed expertise in air, water and soil quality management, analysing onshore, offshore and atmospheric environment, near-space environment, ionospheric chemistry, stratosphere-mesosphere coupling, 'toxic & hazardous' waste management and carrying capacity and environmental impact and risk assessment studies.

Scientific Publications

CSIR publishes 15 primary scholarly science journals – the latest introduction being Indian Journal of Intellectual Property Rights and Journal of Traditional Knowledge. It brings out 10 bulletins on specific science area such as electro-chemistry, fuel science & technology, mining research, mechanical engineering, medicinal and aromatic plant sciences etc.

International Collaboration

CSIR fosters symbiotic S&T cooperation with its counterparts abroad through bilateral and multilateral co-operation and exchange programmes. It has S&T collaborative agreements/arrangements with 30 agencies in 27 countries. It has also been participating fully in the activities of the Commonwealth Science Council, the Association for Science Cooperation in Asia, the South Asia Association for Regional Cooperation, the World Association of Industrial and Technological Research Organizations, the Canadian International Development Research Centre, and the Third World Academy of Sciences (TWAS). With TWAS it operates fellowships, both for post-Doctoral Research and for post-Graduate studies, in CSIR laboratories.



CHAPTER XXVI

Indian Council of Agricultural Research

Agriculture sector occupies the centre stage of India's social security and overall economic welfare. Since Independence, India has witnessed significant increase in foodgrain production (green revolution), oilseeds (yellow revolution), milk (white revolution), fish (blue revolution), and fruits and vegetables (golden revolution). All these became possible owing to the application of cutting edge of science coupled with the positive policy support, and hard work of Indian farmers. The Indian Council of Agricultural Research (ICAR), an apex organization for conducting and co-ordinating agricultural research, has been at the forefront to lead these agricultural revolutions in the country, making India not only self-sufficient in food but also with surplus. As a forward looking organization, fully realizing the emerging complex challenges, ICAR has set a vision to attain 'Rainbow Revolution' covering the entire spectrum of activities in agriculture which will make India a developed nation free of poverty, hunger, malnutrition, and environmental safety. Towards this goal, it is operating two prestigious and mega projects, viz. National Agricultural Technology Project with emphasis on production system research, organization and management reforms and innovations in technology dissemination and Agricultural Human Resource Development Project with emphasis on improving the quality of agricultural education.

> SINCE INDEPENDENCE, INDIA HAS WITNESSED SIGNIFICANT INCREASE IN FOODGRAIN PRODUCTION (GREEN REVOLUTION), OILSEEDS (YELLOW REVOLUTION), MILK (WHITE REVOLUTION), FISH (BLUE REVOLUTION), AND FRUITS AND VEGETABLES (GOLDEN REVOLUTION).

The ICAR began as the Imperial Council of Agricultural Research, an autonomous body (a registered society) in 1929. Presently the Union Minister of Agriculture is the President of the ICAR Society. The Director-General (DG) is the Principal Executive Officer and is also the Secretary to the Department of Agricultural Research and Education (DARE). DARE is the nodal department for all related scientific and development activities and bilateral scientific collaborations with other countries.

The Council has its Headquarters at New Delhi, and a vast network of institutes all over the country, consisting of 45 Institutes, four National Bureau, 30 National Research Centres, ten Project Directorates and

80 All India Coordinated Research Projects. The functions of ICAR are similar to those of University Grants Commission (UGC) in respect of agricultural education. The technical functions of the Head-quarters are grouped into eight subject-matter divisions, each headed by an eminent scientist as Deputy Director-General.

Under the aegis of the ICAR there are 28 state agricultural universities, four deemed-to-be-universities and one central agricultural university, 261 *Krishi Vigyan Kendras* (KVKs: farm clinics) in the rural districts of the country for transfer of technology, and eight trainers training centres. For staff training and addressing research management issues, it has established an institute for human resource development called the National Academy of Agricultural Research Management (NAARM).

ICAR is one of the leading agricultural research and development systems in the world, having 30,000 personnel, with more than 7000 engaged in active research and management.


Photo: H.Y. Mohan Ram

Bajra – Pennisetum typhoides.

The Mandate

The mandate of ICAR is:

- To plan, undertake, aid, promote and coordinate education, research and its application in agriculture, agroforestry, animal husbandry, fisheries, home science and allied sciences.
- To act as clearing house of research and general information through publications and information system, and instituting and promoting transfer of technology programmes.
- To provide, undertake and promote consultancy services in the fields of education, research, training and dissemination of information.
- To look into problems relating to broader areas of rural development concerning agriculture, including post-harvest technology, by developing cooperative programmes with other organizations such as the Indian Council of Social Sciences Research, Council of Scientific and Industrial Research, Bhabha Atomic Research Centre and universities.
- To do other things considered necessary to attain the objectives of ICAR.

Crop Science Division

The Crop Science Division has played a key role in ushering in the era of Green and Yellow Revolutions in the country. It is the largest Division of the Council with focus on the development of improved crop cultivars and appropriate crop production-protection technologies, and basic and strategic researches in crop science. The Division has ten institutes, one bureau, five project directorates, seven national research centres and 30 all India co-ordinated research projects. In addition, a large number of ad-hoc research projects and revolving schemes are also in operation.

Achievements

- Over 2,300 high-yielding varities and hybrids of field crops have been developed, released and notified for their commercial cultivation.

- First in the world to develop hybrid cultivars of cotton, grain pearl millet, pigeonpea, castor and safflower, and second to develop hybrid cultivars of rice and sorghum. Hybrid cotton is a landmark achievement in hybrid research.
- The varieties of foodgrains, particularly that of wheat and rice, have been instrumental in ushering in the area of Green Revolution in mid-60s and sustaining the momentum of productivity enhancement in post-green revolution period.
- The improved varieties played a catalytic role in the adoption of other components of improved technology package, such as fertilizers, pesticides, irrigation water and transforming the mindset of farmers from conservative to technology-responsive ones.
- Incorporation of resistance to diseases and tolerance to abiotic stresses in high yielding background have enabled insulation of crop plants against these stresses and thus provided stability in food production and food security.
- Development of short duration varieties of rice, sorghum, cotton, pigeonpea, chickpea, greengram, blackgram etc. has opened up awareness for multiple cropping systems and helped in enhancing cropping intensity.
- Developed/deployed the concept of new plant type in various crop plants particularly wheat, rice, maize, sorghum etc. to upgrade genetic ceiling of yield potential.
- Spectacular success has been achieved in introduction and improvement of new crops, such as soybean and sunflower. India is now the fifth largest producer of soybean in the world.
- Improved varieties of sugarcane, wheat, rice, maize, sorghum, groundnut, mustard etc. developed in India have been used for commercial cultivation in many other countries.
- Developed new breeding methods, mating designs and analyses, and germplasm screening techniques for evaluation of resistance/tolerance to biotic and abiotic stresses.
- Developed experimental transgenics in cotton and rice by incorporating genes for insect resistance. Also developed protocols for micropropagation.
- The etiology, epidemology and the management of major diseases/insects pests have been worked out, facilitating the forecasting system and in developing location-specific integrated pest management (IPM) modules for sustainable crop production. Protocols have been developed for mass multiplication and release of biocontrol agents.
- Adoption of IMP modules has helped in lowering the quantum of pesticide requirements and promoting non-chemical eco-friendly approaches.
- Established the National Gene Bank at the National Bureau of Plant Genetic Resources, New Delhi, one of the World's leading gene banks, for long-term storage of seed and other planting materials. About 0.20 million accessions have been conserved.
- Steady increase in breeder seed production resulting in enhanced supply of quality seeds to the farmers. About 26,000 q. of breeder seed is being produced annually and supplied for production of foundation seed and in turn certified seed.
- Seed production technologies for various crops refined, particularly with reference to hybrid seed production.
- Developed a unique concept of multi-disciplinary, multi-locational approach in crop improvement in the form of All India Coordinated Research projects which led to synergistic cooperation for the development of widely adapted/location-specific cultivars and production technologies.
- Between 1950-51 and 1998-99, the production of foodgrains increased from 50.8 to 202.5 mt, oilseeds from 5.2 to 25.7 mt, cotton from 3.0 to 12.8 mt and sugarcane from 5.2 to 290.7 mt. The productivity of wheat increased four times and that of rice, maize and cotton three times.

- Development and adoption of new varieties of oilseeds and complementary technologies doubled oilseeds production in a decade (12.6 mt during 1987-88 to 24.4 mt during 1996-97), generally known as the Yellow Revolution.
- Increased food production has transformed the ship to mouth nation of early 1960s into a food secure one with exportable surplus of certain commodities.
- India has become the second largest producer of wheat and rice and is also amongst the top exporters of rice.



Horticulture Division

The Horticulture Division has nine research institutes, 11 national research centres and 15 coordinated research projects.



Photos: H.Y. Mohan Ram

Achievements

- India has emerged as the second largest producer of fresh fruits and vegetables in the world.
- India is presently the largest exporter of spices and cashew.
- A total of 460 high-yielding varieties and hybrids of horticultural crops have been developed. As a result, productivity of banana and potato has gone up three-times each, and cassava two-times.
- Regular bearing mango hybrid, export quality grapes, multi-disease resistant vegetable hybrids, high value spices and tuber crops of industrial use have been developed.
- Substantial increase in production of banana plantlets through tissue culture, use of drip irrigation, chemical regulation of mango flowering and high-density orcharding in fruit crops have been obtained.
- True potato seed (TPS) technology is standardized.
- Low cost environment-friendly cool chambers for on-farm storage of fruits and vegetables have been developed.

Top: Breeding work in mustard is receiving top priority
Bottom: India is the second largest producer of fresh vegetables in the world. Vegetables are an important source of vitamins, minerals, fibre and anti-oxidants in human diet

National Bureau of Plant Genetic Resources

National Bureau of Plant Genetic Resources (NBPGR) was established in 1976 by ICAR, at Pusa Campus, New Delhi. The institute has been vested with the responsibility to plan, undertake and coordinate activities and services related to plant genetic resources including collection, exchange, quarantine, evaluation, documentation, conservation and utilization of crops plants and horticultural plants, their land races and wild relatives. Besides its Headquarters at the Pusa Campus and Experimental Farm at the Issapur village near Delhi, the institute has 12 regional stations/exploration base centers/quarantine stations/satellite stations located in diverse agro-climatic zones of the country. NBPGR is the nodal organization for developing, operating and coordinating the Indian Plant Genetic Resource System. The system comprises base collections of germplasm of different crops kept under long term storage at NBPGR headquarters and a network of over 30 National Active Germplasm Sites located throughout the country. These sites are responsible for evaluation, multiplication and storage of germplasm. NBPGR has been able to build up 2,02,228 accessions from 183 species in its base collections in the National Gene bank (at -20° C) as of June 2001.

Animal Sciences Division

The Division has seven research institutes, one bureau, two project directorates, six national research centres, and 11 coordinated research projects.

Achievements

- A number of new genotypes in cattle – *Karan Swiss, Karan-Fries* and *Frieswal* developed for increased milk production. *Murrah, Nili, Rav*i and *Surti* buffaloes improved for milk production
- Three new high producing strains of sheep for fine wool, carpet wool and mutton evolved; and a strain of *Mohair* goat developed.
- Two hybrids of fast-growing poultry broilers and four high producing layer strains developed and released.
- Various immuno-biologicals, vaccines, immuno-diagnostics, indigenous drugs and medicines against various infectious and non-infectious diseases of livestock and poultry, developed.
- Monoclonals have been developed for the diagnosis of various diseases and reproductive disorders.
- ELISA-based diagnostic tests for various livestock and poultry diseases developed for precise and rapid diagnosis. Effective disease monitoring and surveillance have resulted in reduced morbidity and mortality.
- Process, techniques and equipment for the manufacture of quality milk and dairy products with reliable quality testing methods developed.
- Methods of preparation of different recipes and preservation of meat and eggs developed, and quality testing protocols for egg, meat and meat products standardized.
- Blending of camel hair and Angora rabbit wool with other fibres and converting those into yarn suitable for making finished goods achieved.
- Nutrient requirements of various categories of livestock for different production functions studied and standards set up.
- Technologies for utilization of cereal straws, agro-byproducts, conventional and non-conventional feeds developed area-wise and region-wise.
- Artificial insemination and embryo transfer technology used for improvement of native germplasm, and production and multiplication of elite germplasm.



Photo: H.Y. Mohan Ram

Goats and sheep grazing in a field in Andhra Pradesh

FISHERIES DIVISION

This Division has six institutes, one bureau and one research centre. In addition a good number of ad-hoc research projects and revolving fund schemes are also in operation.

ACHIEVEMENTS

- Blue Revolution has been attained by enhancing fish production from 0.75 million mt in 1951 to 5.4 million mt in 1997.
- India has emerged as the second largest producing country in the world in freshwater aquaculture.
- Phenomenal growth of marine products export.
- Indigenous design of fishing craft and gears.
- Developed national standards for fish inspection and quality control.
- Nutritional evaluation of major fish species and fishery products.
- Created national collection centre for characterization and storage of important marine microorganisms.
- Developed value-added fishery products for export market.
- Technology development of Retortable Pouch Process as a substitute for canning fish.
- Commercial production of chitin and chitosan from shrimp head and shell.
- Hatchery technology for shrimp.
- Semi-intensive shrimp farming.
- Fattening of lobsters and crabs.
- Artificial feed for shrimp farming.
- Technology package for broodstock management, production of fingerlings and grow-out systems for major finfish, shellfish and molluscs.
- Culture and utilization of sea weeds.
- Technology package for mass culture of 11 species of micro-algae.
- Production of ornamental fish under hatchery conditions.
- Breeding of seabass under controlled conditions.
- Commercial production of cultured pearls from pearl oysters.

- Induced breeding of major carps, catfishes and other finfishes.
- Production of freshwater pearls.
- Development of vaccines and formulation of drugs for fish diseases.
- Genetically improved, rohu, CIFA IR-I.
- Commercialization of fish feeds for inland aquaculture.
- Production of *mahseer* and snow-trout in hatcheries.
- Conservation of endangered species.
- Cryopreservation of milts of consumable important fish species.
- Enhanced fish productivity of reservoirs.

Agricultural Engineering Division

The Division provides engineering inputs for mechanization of conventional and protected agriculture, conservation of produce and by-products from quantitative and qualitative losses, and value addition and agro-processing enterprises for additional income and employment, energy management in agriculture and rural living for increasing production and productivity, and reducing drudgery.

Achievements

- Manual, animal and power-operated seeds drills, and planters, weeders; animal drawn multi-purpose tool frame; zero-till/strip-till-drills, till-planters; puddlers; manual and self-propelled rice transplanters; tall tree, orchard, and high clearance sprayers; self-propelled, walking/riding and tractor/ power tiller mounted vertical conveyor reaper; and multi-crop threshers.
- 126 types of agricultural machines developed, of which more than 60 have been commercialized and 23 released for front-line demonstrations.
- Hand-operated groundnut-cum-castor decorticator, low-cost grains, pulse, oilseed mills; power operated straw baler, vegetable dehydrator; manually and power operated dough mixer; rice puffing machine; crop residue fired and solar drier; cleaners, sifters and graders; low cost improved storage structures for foodgrains, evaporative cooled structures for fruits and vegetables.
- Machinery for soybean processing and solid, granular and liquid jaggery developed.
- Technologies for cotton and jute products developed.
- Process for the preparation of shellac, lac dye and wax from lac factory effluents; insulating varnishes, melfolac, primer and paint compositions, shellac bond powder, aleuritic and jalaric acids, perfumery compounds developed.
- Energy efficient equipment and packages; enhanced system efficiency in use of animate power; tractors and power tillers; low cost biogas plants; pyrolysed briquetted fuels; low cost solar cookers and water heaters, solar tracking device; high efficiency cooking stoves; gasifiers for process heat and mechanical power; charcoal briquetting machine; portable charring kiln developed.
- System improvement and safety in centrifugal pumps; solution to corrosion and incrustation in tube-wells; construction of wells in hard rock areas; surface, sub-surface and vertical drainage.
- Establishment of Agricultural Research Information System (ARIS), a WAN connecting 28 State agricultural universities and their 120 zonal agricultural stations, 49 ICAR institutes, 10 project directorates, 25 NRCs and its headquarters in *Krishi Bhavan*.

Natural Resources Management Division

The Division has nine research institutes, one bureau, two project directorates and two national research institutes.

Achievements

- Soil map of the country on 1:7 million scale, state map on 1:250,000 scale and district soil maps on

1:50,000 scale have been prepared. Soil degradation map of the country on 1:4.4 million scale has also been prepared.

- Twenty agro-ecological zones and sixty agro-ecological sub-regions of the country based on physiography, soils, climate, length of growing period and available soil moisture are mapped on 1:4.4 million scale.
- Modification of land configuration on Alfisols, Vertisols and Inceptisols for on-farm rainwater management in rainfed areas.
- An integrated strategy of managing rainfed areas through watershed development projects in several parts of the country.
- Soil and water conservation treatments in mountainous watersheds to runoff and soil loss.
- Off-season tillage to improve moisture conservation and weed control on Alfisols.
- Techniques of sand dune stabilization and shelter belt plantation were developed for arresting the movement of sand dunes in the arid zone.
- Cropping sequences and intercrop combinations developed for irrigated and rainfed areas.
- Water-use efficient irrigation schedules for major crops were evolved resulting in saving of irrigation water.
- Water-use efficient, micro-irrigation methods and technologies for utilization of available water in scarce areas were developed for irrigation, resulting in considerable saving of water and significant increase in crop yields.
- Technology for reclamation of alkali soils has been adopted in 1.0 M ha in Haryana, Punjab and Uttar Pradesh.
- Sub-surface drainage technology developed for waterlogged saline soils in Punjab, Haryana, Rajasthan, Gujarat, Karnataka, and Andhra Pradesh.
- Critical growth stages of various crops and cropping systems with respect to water stress and water requirement have been identified.
- Methodology of artificial groundwater recharge developed for excess groundwater utilization by the use of cavity wells, irrigation-cum-recharge well and by percolation tank in hard rock areas.
- Relay, parallel, multiple and multi-storey cropping systems resulted in improved cropping intensity and productivity.
- Agri-silviculture, agri-silvi-horticulture, agro-horticulture, silvi-pasture systems have been developed and evaluated for different agro-ecological regions.
- Agriculture production strategies developed based on weather forecast.

Agricultural Education Division

The Education Division provides administrative support to the Central Agricultural University (CAU) and the National Academy of Agricultural Research Management and development grants to State Agricultural Universities, CAU, and Deemed-to-be Universities in ICAR.

Achievements

- Establishment of Accreditation Board for quality assurance to clientele.
- Grants of over Rs.760 millions sanctioned to SAUs, Central University and DUs to strengthen and update infrastructure and faculty improvement during VIII Plan.
- Revision and updating of course curricula of all 11 undergraduate (UG) courses completed and adopted by all SAUs.
- Qualifying National Eligibility Test (NET) made compulsory for recruitment at Assistant Professor/Lecturer level.
- To reduce inbreeding and promote cultural exchange, 300 National Talent Scholarships in UG, 437 Junior Research Fellowships (JRF) and 200 Senior Research Fellowships (SRF) are awarded to meritorious students in every academic session.
- 200 foreign students from Iran, Ethiopia, Nepal, Bhutan, Bangladesh, Eritrea, Mauritius, Uganda and Yemen were admitted in UG and PG courses

in 1998-99 academic session.

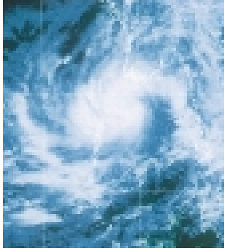
- Organized summer/winter schools in different disciplines to train scientists and faculty members.
- Arranged training programmes under Centres of Advance Studies to train scientists/teachers in current advancement in several areas.
- A workshop was held for writing university level books and 35 titles were finalized.
- National Information System on Agricultural Education (NISAGE) developed.
- Nine National Professors and 25 National Fellows are in position.

Agricultural Extension Division

This is the backbone of the ICAR System for technology assessment, refinement and transfer to the farmers.

Achievements

- 25,000 farmers and farm women are trained every year in agriculture and allied fields such as crop production, plant protection, livestock production and management, soil and water management, farm machinery and tools, and home science.
- Vocational training is imparted to 46,000 rural youth in poultry, dairying, piggery, beekeeping, fisheries, fruit and vegetable preservation, maintenance and repairing of farm machinery and tools, and hybrid seed production.
- In-service training programme to upgrade the knowledge and skills in transfer of technologies in agriculture and allied areas for 2,200 extension functionaries in KVKs and Trainers' Training Centres (TTCs).
- Front-line Demonstration (FLD) on oilseed and pulse crops benefitting 11,000 farmers.
- Training of trainers in frontier areas such as dryland agriculture, animal production, horticulture, freshwater, aquaculture, marine fisheries, hill agriculture, agricultural engineering and women in agriculture in TTCs.
- Multi-locational advance varietal trials of 17 selected crops in 60 centres under irrigated and rainfed conditions under separate cropping sequences in a joint collaborative Technology Evaluation and Impact Assessment Project with Crop Science Division.
- Identification, assessment and development of gender-specific technologies at the National Research Centre for Women in Agriculture, Bhubaneshwar (Orissa). Training of farm women in farm implements and tools at the sub-centre of NRCWA at the Central Institute of Agricultural Engineering, Bhopal (Madhya Pradesh).
- Establishment of 40 Agricultural Technology Information Centres in ICAR Institutes and SAUs. These centres will provide a 'Single Window' delivery system for technology products, services and information available in the institutions to the farmers.



CHAPTER XXVII

INDIAN COUNCIL OF MEDICAL RESEARCH

The Indian Council of Medical Research (ICMR), New Delhi, the apex body in India for the planning, formulation, coordination, implementation and promotion of biomedical research, is one of the oldest medical research bodies in the world. It has completed 90 years of its existence.

The Government of India, as early as in 1911, set up the Indian Research Fund Association (IRFA) with the specific objective of sponsoring and coordinating medical research in the country. After independence, in 1949, the IRFA was redesignated as the Indian Council of Medical Research (ICMR) with considerably expanded scope of functions and responsibilities.

> ICMR USES NGO'S, VILLAGE GUIDES AND EDUCATED YOUTH IN CASE FINDING AND MORE IMPORTANTLY, CASE HOLDING.

The ICMR was constituted as an autonomous organization, with the Union Health Minister as President of its Governing Body. A Scientific Advisory Board comprising eminent biomedical experts assists the ICMR in scientific and technical matters. The Council promotes biomedical research in the country through intramural research (through institutes totally funded by ICMR) and extramural research (through grants-in-aid given to projects in non-ICMR institutes).

Intramural research is carried out currently through the Council's 21 permanent national research institutes/centres and six regional medical research centres. The permanent institutes are mission-oriented laboratories located in different parts of India and address themselves to research on specific health topics such as tuberculosis, leprosy, cholera and diarrhoeal diseases, viral diseases including AIDS, malaria, kala-azar, vector control, nutrition, food and drug toxicology, reproduction, immunohaematology, oncology, medical statistics, etc. The regional medical research centres focus especially on the regional health problems, and also aim to strengthen or generate research capabilities in different geographic areas of the country. In times of national emergencies there could be a coordinated attempt. Thus, many of the permanent institutes and regional medical research centres continue to take part in the sero-surveillance of human immunodeficiency virus (HIV) infection, in addition to their specific fields of research. Apart from research, the permanent institutes are actively engaged in human resource development programmes by imparting training at the younger level through Masters and Doctoral programmes. In addition, many institutes/centers also organize national and international training

courses in specific areas in which the Council's institutes have acknowledged expertise.

Extramural research is promoted by ICMR basically to strengthen the biomedical expertise outside the Council, especially in medical colleges and the University system. This is achieved through (i) setting up Centres for Advanced Research in chosen research areas around existing expertise and infrastructure in selected departments of Medical Colleges, Universities and other non-ICMR research institutes; (ii) Task force studies which emphasize a time-bound, goal-oriented approach with clearly defined targets, specific time frames, standardized and uniform methodologies, and often a multicentric structure; and (iii) open-ended research on the basis of applications for grants-in-aid received from scientists in non-ICMR institutes located in various parts of the country.

Human resource development in biomedical research is encouraged by ICMR through various schemes such as (i) Research Fellowships i.e. Junior and Senior Fellowships and Research Associateships; (ii) Short-term Visiting Fellowships (which allow scientists to learn advanced research techniques from other well-established research institutes in India); (iii) Short-term Research Studentships (for undergraduate medical students to encourage them to familiarize themselves with research methodologies and techniques); and (iv) various Training Programmes and Workshops conducted by ICMR Institutes and Headquarters. For retired medical scientists and teachers, the Council offers the position of Emeritus Scientists to enable them to continue or take up research on specific biomedical topics. The Council also awards prizes to Indian scientists (young as well as established ones), in recognition of significant contributions to biomedical research.

In the context of the changing public health scenario, the balancing of research efforts between competing fields, especially as resources are severely limited, is a typical problem encountered in the management of medical research in developing countries. Infectious diseases, malnutrition and excessive population growth have continued to constitute the three major priorities to be addressed in medical research throughout the past several decades. In addition to tackling these issues, research has also been intensified progressively on emerging health problems such as cardiovascular diseases, metabolic disorders (including diabetes mellitus), neurological disorders, blindness, liver diseases, cancer, mental health etc. Research on traditional medicine/herbal remedies was revived with a disease-oriented approach. Attempts have been made to strengthen and streamline medical informatics and communication to meet the growing needs and demands of the biomedical community. The Council is alert to the emerging challenges in terms of new diseases and new dimensions of existing diseases. The rapid organization of a network of Surveillance Centres for AIDS in different states of India in 1986 exemplifies this.

Two broad lines of research endeavour have been focussed in ICMR in the last two decades (1) application of available knowledge, under the prevailing socio-economic and cultural environment through Health Systems Research involving interdisciplinary efforts between biomedical, social and behavioural sciences with epidemiology acting as a bridge, and (2) application of the powerful tools of modern biology to search for the causes and also to unravel basic mechanisms and to identify risk factors leading to early diagnosis and development of new therapeutic agents including vaccines.

Major Contributions & Achievements

During the nine decades of its existence, the ICMR has had several significant and path-breaking achievements to its credit and many of the research findings of the past have laid basis/foundation for formulating and launching several National Health programmes and Disease Control Programmes.

Communicable Diseases

Tuberculosis (TB): The efficacy and safety of short course chemotherapy (SCC) in pulmonary,

extra-pulmonary, and multi drug resistant (MDR) forms of affliction in adult and childhood tuberculosis have been demonstrated by the Council's Tuberculosis Research Centre (TRC), Chennai and SCC has been introduced in the National Tuberculosis Control Programme. An important breakthrough in the management of tuberculosis of spine without paraplegia has been achieved using ambulatory chemotherapy for six or nine months with daily isoniazid and rifampicin. A large scale community based double blind randomized controlled trial carried out in south India to evaluate the protective effect of BCG demonstrated that it did not offer any protection against adult forms of bacillary pulmonary tuberculosis. The Council has also achieved effective and optimal utilization of non-governmental organizations (NGOs), village health guides and students in urban areas and educated youths in tribal areas in case finding and more importantly, case holding. The TRC, Chennai has also demonstrated that supervised administration of anti-TB drugs twice weekly is as efficacious as daily self-administered treatment. The directly observed treatment short course (DOTS) is currently a globally accepted programme for control of tuberculosis.

ICMR HAS DEVELOPED GUIDELINES FOR ART TO HELP INFERTILE COUPLES WHICH INCLUDE LEGAL AND ETHICAL ASPECTS ALSO.

Leprosy: The Central JALMA Institute for Leprosy (CJIL), Agra is responsible for the Council's main research activities on chemotherapy, immunology, pathology and biochemistry of leprosy. The main thrust of research in the area of leprosy now is to reduce the infection load in the community by introducing effective multi-drug therapy (MDT) and testing appropriate vaccines against leprosy.

A controlled, double blind, randomized, prophylactic leprosy vaccine trial was conducted in south India very recently. Four vaccines, viz. BCG, BCG + killed *Mycobacterium leprae*, M.w. and ICRC were studied in comparison with a normal saline placebo. From about 3,00,000 people, 2,16,000 were found eligible for vaccination and among them, 1,71,400 volunteered to participate in the study. Intake for the study was completed in two and a half years from January 1991. There was no instance of serious toxicity or side-effect subsequent to vaccination. All the candidate vaccines were safe for human use. Decoding was done after the completion of the second resurvey in December 1998. Results for vaccine efficacy are based on examination of more than 70% of the original 'vaccinated' cohort population, in both the first and the second resurveys. BCG + killed *M. leprae* provided 64% protection (95% CI 50.4–73.9%), ICRC provided 65.5% protection (95% CI 48.0–77.0%), M.w. gave 25.7% protection (95% CI 1.9–43.8%) and BCG gave 34.1% protection (95% CI 13.5–49.8%). Protection observed with the ICRC vaccine and BCG + killed *M. leprae* vaccine meets the requirement of public health utility and these vaccines deserve further consideration for their ultimate applicability in leprosy prevention.

The concept of multi-drug therapy for leprosy was also field tested and evaluated. Pulsed rifampicin administration was observed to be therapeutically as good as daily or intermittent administration. A MDT regimen supplemented with one year of pyrazinamide administration has been found to have effect on persisters and subsequent faster bacteriological clearance. A MDT of longer duration for patients not responding to six months regimen has been recommended. Combined chemotherapeutic and immuno-therapeutic regimens have been designed and found to enhance killing and clearance of bacilli. These have been

found effective to reduce the duration of treatment especially in cases with high bacterial load. A new regimen comprising conventional MDT together with newer drugs like ofloxacin and minocycline has been found to be safe and well tolerated. Single dose of rifampicin, ofloxacin and minocycline (ROM) has been shown to be as effective as six months of MDT for patients with mono lesion leprosy.

Immuno-diagnostic tests (FLA-ABS, SACT-ELISA, PGL-ELISA, etc.) have been developed/tested for detection of sub-clinical infections and monitoring of chemotherapy in patients with multi-bacillary leprosy. Improved techniques for prevention and surgical correction of deformities of the hands and feet have been developed. Some probes targeting rRNA of *M. leprae* and a quantitative hybridization (microdensitometry) have been developed. These ribosomal RNA probes and rRNA-PCR techniques have been demonstrated to correlate with viability and diagnosis of active disease. This strategy shown for the first time by the ICMR is an accepted concept now.

A Mycobacterial Repository Centre has been established at the CJIL, Agra to serve as a source of reference, indigenous strains as well as for epidemiological characterization of mycobacteria.

Diarrhoeal Diseases: The main thrust of Council's National Institute of Cholera & Enteric Diseases (NICED), Kolkata has been on continuous and in-depth study of diarrhoeal diseases and to suggest remedial measures. This institute was designated as the WHO Collaborating Centre for Research & Training in Diarrhoeal Diseases in 1980. The major achievements in the area of diarrhoeal diseases are summarized below:

The demonstration that oral rehydration therapy could prevent mortality due to diarrhoeal diseases was an important milestone. Home available fluids (HAF) such as Sherbat (salt, sugar, lemon either singly or in combination) or tender coconut water, pressed rice water has been found to be equally effective and more acceptable than oral rehydration solution (ORS). The use of hypo-osmolar oral rehydration solution (R-Hypo-ORS) reduced the total fluid requirement and loss of fluids in stools in comparison to WHO-ORS. The feasibility and effectiveness of managing cases of dehydrating diarrhoeal diseases according to their severity at various levels of health care facility was demonstrated. This has led to 3-tier approach of managing acute diarrhoea in the Diarrhoeal Disease Control Programme.

A new toxigenic strain of *Vibrio cholerae - V. cholerae* 0139 -was detected and characterized and its epidemiology elaborated. A new phage typing scheme for *V. cholerae* biotype Eltor strain has been developed. This could be used as an epidemiological marker for tracing the source of infection. A new recombinant cholera vaccine was developed in a collaborative effort with other sister agencies in India. This vaccine has been successfully tested in animal model and has completed Phase 1 and limited Phase 2 clinical trial.

An enteroaggregative *Escherichia coli* (E Agg EC) has been isolated as a possible etiological agent of acute diarrhoea among children in Kolkata. It was isolated more frequently from children less than 36 months of age.

The emergence of rotavirus causing diarrhoea in adults in Kolkata is a new phenomenon. The group B rotavirus resembles the Chinese adult

National Health Programmes

- National Malaria Eradication Programme
- National Filaria Control Programme
- National Leprosy Control Programme
- Diarrhoeal Diseases Control Programme
- National AIDS Control Programme
- Iodine Deficiency Disorders (IDD) Programme
- National Cancer Control Programme
- Universal Immunization Programme
- National Tuberculosis Programme

diarrhoea rotavirus (ADRV) strains in electrophoretic profile. An immuno-diagnostic kit was developed for diagnosis of rotavirus infection.

Vibrio parahaemolyticus strains belonging to serotype 03.IC6 emerged in Kolkata. This strain has been studied using different molecular techniques such as ribotyping-genotyping by restriction fragment length polymorphism (RFLP) and pulsed field gel electrophoresis. No RFLP in the encoding region of the thermostable direct haemolysis (TDH) was observed. These strains predominantly belonged to one clone.

Viral Diseases: Research in the area of viral diseases is being conducted at the Council's National Institute of Virology (NIV), Pune, Enterovirus Research Centre (EVRC), Mumbai, National AIDS Research Institute (NARI), Pune and Centre for Research in Medical Entomology (CRME), Madurai. The Council is supporting research in a wide range of viral diseases including HIV, hepatitis, Japanese encephalitis (JE), poliomyelitis etc.

Cell culture from mosquito (*Aedes albopictus*) tissues was established for the first time in the world at NIV, Pune. These are being used world-wide for arboviruses studies. An effective surveillance system for detection of JE virus (which incorporates monitoring of vector density and serological evidence of virus activity in sentinel animals) has been established which has been taken up by the state of Tamil Nadu. This system will help in timely action in case of impending outbreak. Effectiveness of a strategy using water and environmental management and neem coated urea for control of vector population in the rice fields has been demonstrated. Efficacy of deltamethrin impregnated poly-propylene curtains against vectors of JE at least for five months has been demonstrated.

Kyasanur forest disease (KFD) in the Sagar-Soraba area of Shimoga district in Karnataka was discovered in 1957. Vaccine against KFD was prepared and technology has been transferred for preparation of KFD vaccine to the State Government.

Indigenous ELISA kits for the diagnosis of hepatitis A and B infection and for Group A rotaviruses from human and animals have been developed by the Council's institutes. An IgM Antibody capture (MAC) ELISA kit has also been developed for the detection of flaviviruses [JE, West Nile (WN) and Dengue]. An immuno-diagnostic kit (Dipstick test) has been developed to detect IgM antibodies against dengue virus infection in human. For some of these diagnostics, technology transfer has already been made to industry partners. For others, active efforts are being made to find suitable industry that will take up the responsibility of commercialization. A large panel of mouse monoclonal antibodies has been developed against JE, WN, Dengue (DEN), Chikungunya (CHIK) and rabies viruses, which may lead to the development of numerous commercial viral diagnostic kits. Genotyping of JE virus on the basis of partial nucleotide sequencing was done and derived amino acid sequence of some Indian JE virus strains and phylogenetic relationship have led to identifying four major groups of JE viruses. Sequencing of relevant regions of DEN genome is being done to understand the genetic basis of emergence of different biotypes of dengue virus. A novel DNA virus termed as transfusion-transmitted virus (TTV) was found to be prevalent in India, transmitted mainly by non-parenteral routes and probably not an important cause of chronic liver diseases. Several cell lines have been developed for arboviruses and hepatitis viruses to be used for basic and diagnostic purposes. Clinico-epidemiological and serological studies done by NIV, Pune indicated a new hepato-renal neuropathy syndrome associated with measles.

The ICMR demonstrated the presence of HIV infection in India and initiated country-wide sero-surveillance. The information so obtained on the magnitude of HIV infection and major modes of its transmission has became the basis, first for drawing up the national medium-term plan for AIDS control in

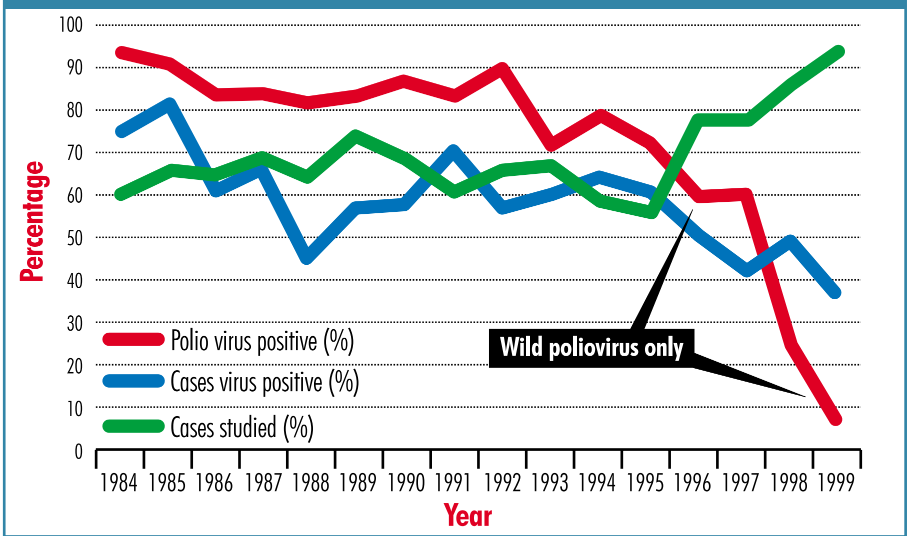
India and later for setting up the National AIDS Control Programme (NACP). Studies carried out by the Council led to the detection of HIV epidemic in injecting drug users in north-east (NE) India and initiation of intervention programmes. The presence of HIV-2 has been detected in India, which led to the incorporation of HIV-1, and HIV-2 screening tests in the NACP. Studies carried out in Manipur showed that in HIV infected individuals, herpes zoster had a high positive predictive value and could serve as a surrogate marker for HIV in areas where injecting practices are very common. HIV-1 subtype analysis was carried out for the first time in India by Heteroduplex Mapping Analysis (HMA) and the studies revealed that 96% samples were of subtype C. The other subtypes prevalent in India are B and A.

Poliomyelitis: Absence of paralytic poliomyelitis due to wild poliovirus infections and absence of wild poliovirus from the environment are essential components of polio eradication. An environmental surveillance study has been initiated using transgenic mouse cell line (L20 B) for virus detection. Poliovirus types 1 and 3 wild viruses were detected indicating the sensitivity and applicability of environmental surveillance.

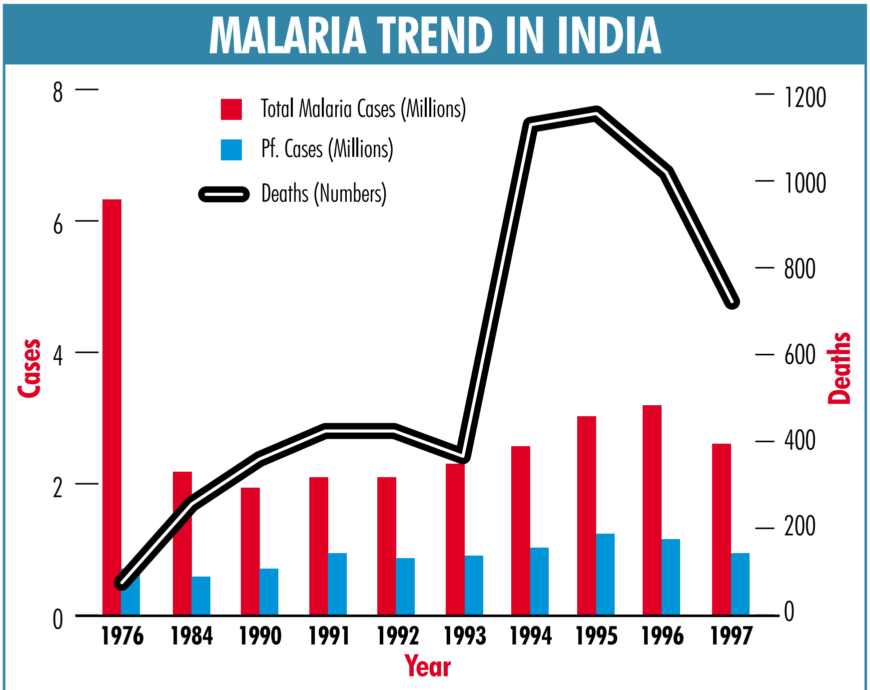
Nucleotide sequence comparison has helped to determine genomic relationship among virus isolates. Sequence data of 72 wild poliovirus type 1 strains circulating in 13 states of India during 1997-98 have been generated. Sequences of wild poliovirus type 1 isolates from India and Bangladesh were also compared. As per the definition of genotypes, isolates from both countries are independent of a single major genotype. Wild poliovirus type 2 transmission has been eliminated from most parts of India and two distinct groups of wild poliovirus type 3 have been found in India.

Malaria: Extensive field, basic and applied research has resulted in recognition of malaria paradigms in the country. New epidemiological paradigms have been formulated and are being used for the national malaria control strategy to review drug policy, insecticide policy and re-organization of the National Anti Malaria Programme (NAMP). A rapid, simple manual immuno-chromatographic technique (ICT) has been validated for detection of *Plasmodium falciparum* histidine rich protein (HRP) for on the spot diagnosis of this malaria in the field. Remote sensing and geographical information systems were used to reveal malaria transmission dynamics at the local level. Cytogenetic studies in sibling species and combination of malariogenic indices and entomological parameters have helped in the malariogenic stratification of the country, which has provided vital information for the NAMP. A Malaria Parasite Bank has been established at the Malaria Research Centre as a centralized facility supported by DBT to cater to the needs of scientists and researchers.

POLIO VIRUS ISOLATION FROM CASES OF FLACCID PARALYSIS MUMBAI 1984 TO 1999



Bioenvironmental methods of malaria control and other technologies in vector control were developed and applied in different geo-ecological sites in the country which are sustainable, free from ecological hazards and are also economical. This has provided a feasible alternative to the insecticide-based approach to control malaria. The indigenous, economic and environmentally compatible neem products were found to be effective for their larvicidal impact against *Anopheles stephensi*, *Culex quinquefasciatus* and *Aedes aegypti*. Mats containing neem oil were found to be effective repellents similar to allethrin mats which are ready for commercialization. The malaria situation is deteriorating in terms of morbidity and moratility due to increase in *P. falciparum* incidence and drug resistance in *P. falciparum* and *P. vivax*. The broad approach to fulfill the objectives of roll back malaria is prevention.



(Source: The Changing Face of Malaria, Ranbaxy Science Foundation, New Delhi, 1998)

Filariasis: A community based integrated vector management programme achieved significant reduction in vector density in Cherthala, Kerala. No new infection of brugian filariasis in age group 1 to 7 has been reported in this area since 1990. This community oriented control programme is a unique example of inter-sectoral coordination where government and non-government agencies have worked together for success of the programme. Biological control of mosquitoes with a biocide *Bacillus sphaericus*, has shown specific larvicidal action especially against *Culex quinquefasciatus* in polluted breeding habitats. Extracts of *Anacardium* sps. have been tested for anti larval and anti pupal activity to control mosquito breeding. A slow release microgel formulation of *B. thuringiensis* var. *israelensis* has been validated for reducing the larval density of *C. quinquefasciatus* in cess pits, cess pools and disused wells. A Cell has been set up at Vector Control Research Centre, Pondicherry for studies linked to elimination of lymphatic filariasis from India using Community Based Mass Control (CBMC) programme and comparing effects of DEC alone and DEC + albendazole.

Leishmaniasis: Simple, cost effective, easy to prepare culture media were developed for *in vitro* maintenance of *Leishmania promastigotes*, based on hemin or haemoglobin powder/clotted and dried rabbit blood on filter paper or fresh blood. It is completely autoclavable and can be used in an ordinary laboratory. Direct Agglutination Test (DAT) was established as early diagnostic tool for Kala-azar.

Clinical trials with combination of pentamidine and SAG (sodium antimony gluconate) in reduced dosage showed effective results similar to therapy with pentamidine alone but without any serious side-effects. Double drug combinations using pentamidine and allopurinol in reduced dosage were found to be better tolerated and showed good results when compared to pentamidine and SAG and pentamidine alone.

Leptospirosis: The Council's RMRC, Port Blair has done a sero-prevalence study of leptospirosis among the tribal population of Andaman and Nicobar Islands. A LEPTO dipstick assay was evaluated at RMRC and compared with IgM ELISA. This test has good sensitivity (78.7%) and specificity (88.3%) and was simple to use with stable shelf life of reagents. Various risk factors associated with acquiring leptospiral infection were also studied. RMRC, Port Blair has been providing referral services for the diagnosis of leptospirosis to other states of the country.

Tribal Health: Studies on the health, morbidity and mortality pattern and the nutrition profile of all the seven tribal groups (*Abujhmarias, Balgas, Birhor, Bharias, Kamars* and *Hill Korwaas* and *Saharlyas*) of Madhya Pradesh have been carried out. The prevalence of yaws was found to be 7% in *Abhujmarias* and goitre was a major public health problem in *Baigas* specially in children below 15 years. A drug delivery strategy has been developed and tested involving traditional healers of tribal communities as link workers in the state of Orissa.

Reproductive Health

The Council's research efforts in the field of reproductive health are mainly conducted by the Institute for Research in Reproduction (IRR), Mumbai, which is now reknowned for its contributions in both basic and applied research. The Institute's work on inhibin and its potential application for male contraception are now widely recognized and cited extensively. The IRR's major focus is on three important leads in the area of male fertility regulation, viz. Human seminal plasma inhibin (HSPI), 80 kDa and 26 kDa proteins. The other activities include basic aspects of male and female fertility regulation, immuno-contraception, infertility, reproductive tract infection, diagnostics and operational researches on the fertility attitudes of men. Human sperm antigen, 80 kDa, has been identified from human sperm extract and efforts are ongoing to develop this peptide as an immunogen for developing anti-fertility vaccine. Efforts are being continued to develop intigrin as a clinical marker to assess the fertility potential in men. Resazurin Reduction Test (RRT) for evaluation of semen quality has been developed and validated. RRT is a simple, rapid, cheap and sensitive test, which is useful in diagnosis of infertility in men.

Based on the results of the clinical trials on several intrauterine contraceptive devices (IUCDs) CuT 200 was recommended in 1975 for use in the National Family Welfare Programme (NFWP). Multicentric clinical trials and pre-programme introduction studies were carried out through the network of human reproduction research centres (HRRCs) to evaluate newer contraceptives for their possible use in the programme; newer methods included improved intrauterine devices (CuT220C, CuT380A, CuT380Ag, LNG IUD), injectable contraceptives (200 mg NET OEN (2-monthly) and combined monthly injectable), subdermal implants (Norplant II 2 rods) and Norplant (6 capsules), triphasic oral pills, non-steroidal weekly oral pill (Centchroman), non-surgical methods for female sterilization, barrier methods (diaphragm, vaginal pessary), Billing ovulation method of natural family planning. Study on Sequelae of Female Sterilization carried out on 32,000 women indicated that Minilap may be recommended for National Family Welfare Programme as it is more efficacious and safer than laparoscopic sterilization under field conditions. The ICMR has prepared national guidelines for tubal sterilization by laproscopy and minilap methods after studying the sequelae of female sterilization. Collaborative research efforts done for *in vitro* fertilization and embryo transfer among infertile couples has been of significant benefit.

Immunodiagnostic kits for urinary esterone glucuronide, pregnanediol glucuronide, luteinising hormone and follicle stimulating hormones have been prepared and evaluated. Some of these kits have been commercialized. A low cost, high sensitivity test for pregnancy detection has also been developed and is in the process of being commercialized.

Two new diagnostic techniques viz. ELISA for Hb

A2 for beta thalassaemia and FISH technique for detection of specific DNA sequence in morphologically preserved cells and tissues have been standardised. These techniques are being converted into user-friendly kits so that these could be used at peripheral hospitals.

Optimal time and safe procedures for medical termination of pregnancy (MTP) were recommended and non-surgical methods for MTP were evaluated. RU-486 in combination with PGE vaginal gel was found to be successful in 90% of women who sought termination of early pregnancy. Use of slow cervical dilator prior to vacuum suction during first trimester MTP was evaluated. Information on the extent of illegal abortions in India was generated.

Maternal & Child Health

Studies were conducted in rural and urban-slum communities in various parts of India for the identification of high-risk mothers and fate of their offsprings. The risk factors identified were – maternal age (< 18 or more than 35 years), parity (primi para), bad obstetric history (1 or more abortion/still birth), preterm birth (less than 37 weeks), maternal anaemia, previous pre-term or low birth weight baby, birth interval (less than 2 years), previous foetal and neonatal mortality, low birth weight (less than 2000 g). Based on the results of these studies suitable intervention strategies were worked out to improve coverage and quality of MCH and FP services at PHC level using comprehensive health care package and high-risk approach. This approach has demonstrated significant improvement in antenatal coverage, referral of high-risk pregnancies and quality of care.

Maternal mortality and reproductive morbidity of women were studied both in the hospital based and community based settings. The studies showed that about two-third of these deaths occurred before reaching health care facility. Major causes of death were haemorrage, sepsis, pregnancy induced hypertension and anaemia.

Clinical and ultrasonographic foetal growth parameters were developed. Feasibility of providing genetic counselling and identification of referral has been successfully established in the peripheral hospitals in the country. The Council has also evaluated the quality of family welfare services at the PHC level.

The ICMR has prepared guidelines for Assisted Reproductive Technology (ART). These Guidelines have addressed several issues such as screening of infertile couple, selection criteria for candidates for ART, selection of donor, informed consent, procedures used, legal and ethical aspects. Infrastructure and training required, accrediting and registry, establishment of protocol and maintenance of records were also addressed in this study.

Scientists at IRR, Mumbai were the first ones in the country to report scientifically documented delivery of a baby using *in vitro* fertilization procedure. The institute continues to offer infertility services and train the doctors from other institutes in ART techniques.

Nutrition

The Council's research efforts in the field of nutrition are in consonance with National Nutrition Policy and have been directed to combat malnutrition and promote nutritional well being. This is achieved through continuous research, monitoring, extension education and training carried out by the National Institute of Nutrition (NIN), Hyderabad and the network of National Nutrition Monitoring Bureau (NNMB).

NNMB has been continuously providing national data on dietary intake and nutritional status of population groups from different parts of the country. The studies indicate that about 30% of the households consume less than 70% of energy requirement. Dietary micronutrient deficiency particularly vitamin A and iron is widespread. About 80% of the individuals consume less than half their requirements. The studies revealed that half of the children are underweight and half of the adults and elder suffer from chronic energy malnutrition. Nutritional status of tribals is worse than their rural counterpart.

More than 650 types of different categories of

foods – cereals, millets, pulses, oils and fats, vegetables, milk and its products, fruits etc. have been analysed for the content of their energy, protein, fat, vitamins and minerals. Information generated by this activity is compiled in the well acclaimed publication - Nutritive value of Indian foods.

The indigenous sandwich ELISA method, developed at NIN, for the assay of serum transferrin receptor (STfR) was found to be a good indicator of iron status.

The Council's National Centre for Laboratory Animal Sciences (NICLAS) located at the NIN, Hyderabad is one of the major centers of its kind in India disseminating knowledge on the care, breeding and management of laboratory animals and their use in biomedical research. The NICLAS scientists have identified several natural mutants in mouse which are good models for drug development and chronic diseases such as – diabetes, tumours, cancers, infertility and obesity.

Non - Communicable Diseases

Oncology/Cancer: The National Cancer Registry Programme (NCRP) set up in 1982 has provided long term community based data on the occurrence of various types of cancers in India. The NCRP continues to generate data on the national cancer status in India The operational feasibility of early detection of cervical cancer by para-medical workers through Pap smear screening and visual inspection of the cervix was established.

Cardiovascular Diseases: Secondary prophylaxis for rheumatic heart disease (RHD) with three-weekly penicillin injections has been demonstrated and a module for detection and management of sore throat, rheumatic fever (RF) and RHD utilizing the PHC infrastructure has been developed. A *Jai Vigyan* Mission mode project on RF/RHD control has been initiated.

The prevalence of coronary artery disease (CAD) and distribution of risk factors for CAD were established. Prevalence of CAD and population distribution of known risk factors was low in rural as compared to urban areas. A multicentric case-control study has been initiated at four centres to identify the factors and quantify the association of risk factors with acute myocardial infarction.

Ophthalmology: The magnitude of blindness problem in various parts of the country has been determined. These data formed the basis for National Programme for Control of Blindness (NPCB). Prevalence of cataract has been determined in various parts of the country and data are being used in promoting eye camp approach in NPCB. Risk factors (use of cow dung and wood fuels and systolic blood pressure towards higher side within normal range) for cataract have also been identified.

Environmental & Occupational Health: Cardiac toxicity in humans as well as in experimental animals due to methomyl in pesticide spray has been described which has resulted in active consideration of banning of this pesticide by Government of India. Prevalence of occupation pneumoconiosis in high proportion has been described in Ladakh region of Western Himalayas. A multi-method ergonomics review technique for work systems analysis and design has been developed. Commissioning and standardization of acoustic, illumination and climatic chambers were done and data provided to set safe limits of exposure to noise, illumination and heat respectively.

Mental Health: Data have been generated on the magnitude of psychiatric problems in the country through community-based surveys. The Council's research on the integration of mental health care with general health care facilitated the formulation and implementation of the National Mental Health Programme.

ICMR has also generated data on prognostic outcomes of psychiatric disorders in India through longitudinal studies. The study of acute psychosis led to inclusion of a new diagnostic category in ICD-10. The Council has developed measurement tools for health such as for assessment of quality of life at

the individual, family and community levels, and also developed measures of psychosocial stress.

A community based epidemiological study of child and adolescent psychiatric disorders in rural and urban areas found the prevalence and type of psychiatric disorders and generated data on psychosocial correlates of childhood psychiatric disorders and on felt treatment need of the community. The Centre for Advanced Research on Health Consequences of Earthquake Disaster with special reference to Mental Health found that there was excess psychiatric morbidity in earthquake affected Marathwada region as compared to control areas.

Neurophysiology: The Neurophysiology Research Unit established in 1950s carried out several path-breaking studies on the intricate mechanisms for coordinating the physiological activities of the central nervous system. The mechanisms regulating hunger involving the two centres, one regulating food intake and the other inducing satiety were rigorously investigated.

Further studies on the role of hypothalamus on cardio-vascular. and respiratory activities showed its wide influence on the various bodily activities including hormonal activity relating to reproductive function. Further, with collaboration from neurologists, pioneering studies were initiated on Yoga. This group provided for the first time unequivocal scientific basis for the positive influence of Yoga on human health. Some of these studies are being followed up even today. This group expanded their attention on the high altitude physiology. Their findings on the hypoxia, acclimation strategies and the physiological adaptation to high altitude and cold temperature were utilized by defense medical officers attending to the soldiers in these areas.

Neurological sciences: Multicentric, clinical and epidemiological studies were undertaken on epilepsy, head injury, peripheral neuropathy, subarachnoid haemorrhage and Landry's Guillian Barre (LGB) syndrome. The clinical presentations and associated etiological factors in these disorders were studied. The study on subarachnoid haemorrhage disproved the widely held contention that aneurysms were extremely rare in India as compared to Western countries. Over one-fourth of all patients studied had aneurysm. There was also a preponderance of men to women in the ratio of 3:2. In addition, people from the North and Western India showed more atherosclerotic lesions in the Circle of Willis, as compared to the people based in the South.

A multicentric collaborative study was also taken up on stroke and ischaemic heart disease in the young and old populations of India. It was shown that, in contrast to the condition in the Western countries, nearly 30% of all strokes in India occurred in young subjects below forty years and ischaemic heart disease in the young constitutes about 15 to 20 per cent.

Haematology: A new blood group, the Mumbai group was discovered by the Council's Institute of Immunohaematology, Mumbai. A globin chain synthesis technique and chorionic villus sample biopsies have been developed for the prenatal diagnosis of thalassaemia and other haemoglobin-opathies. Prevalence of thalassaemia trait and also of haemophilia has been determined. The findings of biochemical and molecular studies on red cell glucose-6-phosphate dehydrogenase (G-6-PD) deficiency in India brings out the fact that the deficiency is heterogeneous in nature as opposed to the common belief that it is only the Mediterranean type which is prevalent in India. The Council's studies also led to the discovery of two new G-6-PD variants namely G-6-PD Rohini and G-6-PD Jamnagar. The ICMR carried out detailed survey in tribal populations in different parts of India particularly in Madhya Pradesh and based on the information collected a *Genetic Atlas of Indian Tribes* has been prepared. The Council's Centre for Advanced Research for Bone Marrow Trans-plantation for Thalassaemia at Vellore completed bone marrow transplantation in 51 cases of thalassaemia major with a success rate of 72.5% comparable to anywhere else in the world. This is now the only Centre in the country, which is able to

offer services from antenatal diagnosis to bone marrow transplantation for thalassaemia major.

Pathology: Thrust areas of research consist of tumour biology (breast cancer, genitourinary malignancies, lymphoma), infectious diseases (chlamydia, leishmaniasis, tuberculosis), reproductive biology, Indian childhood cirrhosis, and environmental biology. Teaching material in the form of microscopic slides, colour transparencies in different branches of pathology has been prepared and distributed.

Traditional Medicine: Through multicentric clinical trials, the ICMR has demonstrated that *Kshaarasootra* (a medicated Ayurvedic thread) technique is a safe, acceptable, cost-effective, non-surgical and ambulatory alternative to surgery for the management of fistula-in-ano. Studies on the use of wood of the Vijayasara (*Pterocarpus marsupium*) in the control of diabetes mellitus has provided highly encouraging results.

Publication, Information & Communication

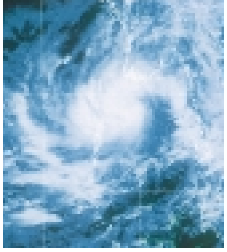
The Indian Journal of Medical Research (IJMR), one of the oldest biomedical Journals of the country has completed 88 years of its publication. A large number of special issues/supplements on important biomedical topics have been published. The Integrated Research Information System (IRIS) was set up in early 1980s to provide information on inventories of scientists, information on extramural projects funded by the ICMR publications. The IRIS has been upgraded into a Bioinformatics Centre in New Delhi with strong communication links between ICMR Institutes and ICMR headquarters. A website has been created for the ICMR (http://icmr.nic.in). The ICMR-NIC Centre for Biomedical information has been identified as the Indian MEDLARS Centre. The Centre has developed IndMED, a database on the Internet, of Indian biomedical publications not included in major international databases.

Ethical Guidelines

The need for uniform ethical guidelines for research on human subjects is universally recognized and the Council has prepared national guidelines on this. In the year 2000, the Council released a comprehensive document entitled Ethical Guidelines for Biomedical Research on Human Subjects.

International Collaboration

The ICMR coordinates the processing, implementing and monitoring of biomedical research programmes carried out under the auspices of either bilateral agreements between India and countries such as USA, UK, Russia and other CIS countries (formerly the USSR), France, Germany or as assistance from international agencies such as the WHO, Ford Foundation, Rockefeller Foundation, NIH, World AIDS Foundation (WAF), UNDP, IDRC, etc. Proposals received from various national laboratories in India are subjected to a rigorous peer review process followed by appropriate clearances from the Government of India. These programmes are intended to facilitate and promote biomedical research in areas of mutual interest to India and other countries/international agencies, with transfer of technology being one of the prime objectives. The facilities available and the modalities of operation vary according to the country or agency concerned. Other Departments/Agencies of the Government of India also deal with similar programmes, foremost among them being the DST, DBT, CSIR, etc. The ICMR offers consultation to other organizations and interacts with agencies for the approval of proposals dealing with biomedical research for implementation. Information on specific procedures for international collaboration/assistance in biomedical research is available with the Indo-Foreign Cell of the ICMR.



CHAPTER XXVIII

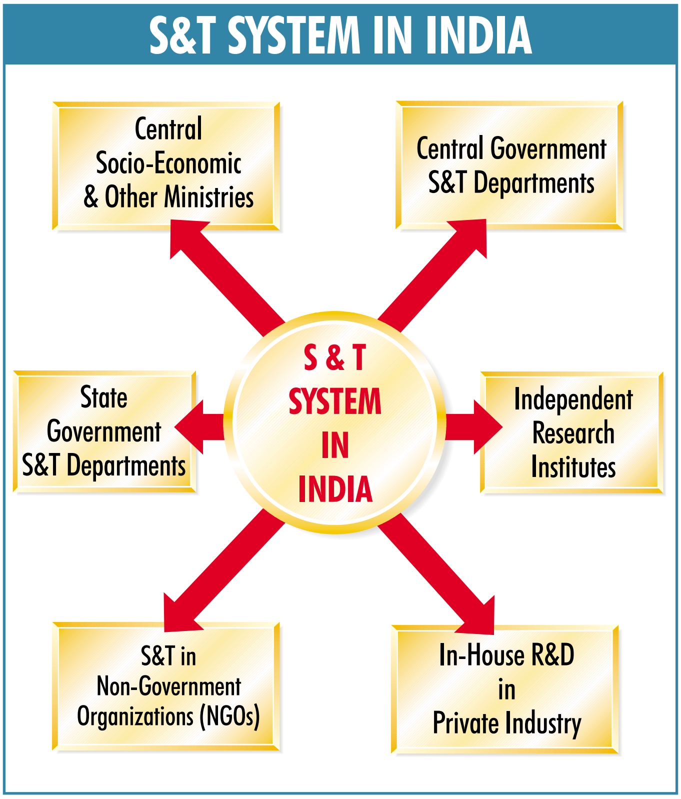
DEPARTMENT OF SCIENCE AND TECHNOLOGY

Science and Technology (S&T) have always been an integral part of Indian culture. Natural philosophy, as it was termed in those ancient times, was pursued vigorously at institutions of higher learning. The Indian Renaissance, which coincided with our independence struggle, at the dawn of 1900s witnessed great strides made by Indian scientists, who have left indelible imprints on the world S&T scene.

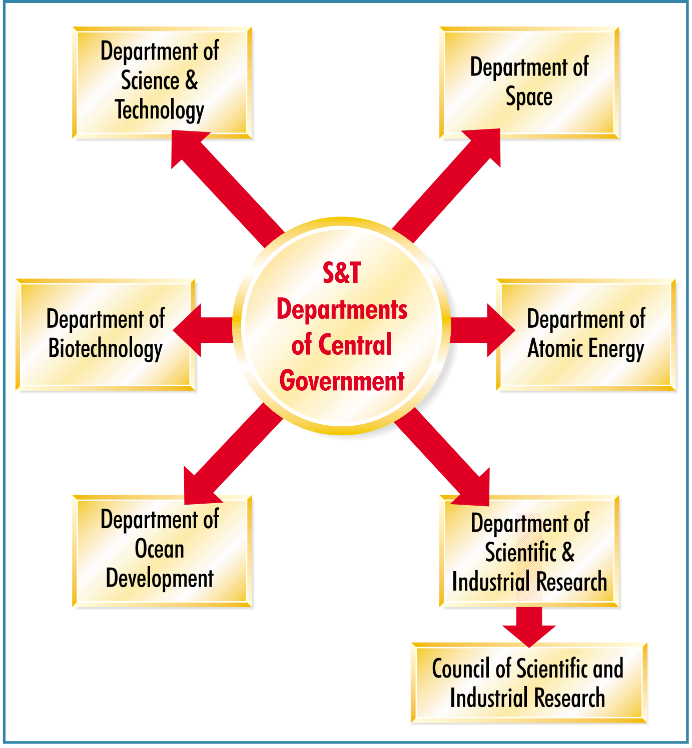
This innate ability to perform creatively in science came to be backed with an institutional set-up and strong state support after the country's independence in 1947. Since then, the Government of India has spared no effort to establish a modern S&T infrastructure in the country. The Government firmly believed that S&T would be the twin tools that would help bring about social equality and economic development to enable India join the mainstream of world community. This conviction was reflected in the Scientific Policy Resolution (SPR) of 1958.

Several scientific departments were set up by the Government of India with specific objectives. These organizations at once met the immediate social needs even as they allowed the country to leap-frog into the modern high-tech world. The Department of Atomic Energy (DAE), the Department of Science and Technology (DST) and the Department of Space (DOS) were among the first S&T departments in the country with the Prime Minister himself or herself taking the reins.

The DST, which was established in May, 1971, has the important objective of promoting new areas of science and technology and to be the nodal department for coordinating those areas of science and technology in which a number of institutions and departments have interest and capabilities. Thus, the DST has a unique role in promoting basic research and technology development in the country. The DST also assists in formulation of policy statements and guidelines on S&T and has



CENTRAL GOVT. S&T DEPARTMENTS



acted, till recently, as Secretariat to apex advisory bodies of Government of India on S&T.

The DST's success in promoting new areas of S&T are best appreciated when one realizes that several unique agencies and departments were formed after hiving off promotional activities from DST after their reaching a stage of criticality. The National Remote Sensing Agency (NRSA) (now transferred to DOS, 1975), Department of Environment (1981), Ministry of Non-Conventional Energy Sources (1982), Department of Ocean Development (1981), Department of Scientific and Industrial Research (1985) and Department of Biotechnology (1986) were all, at one time, part of DST's promotional activities.

While other S&T departments have focused domains of activity, DST's mandate is broader. It draws upon the scientific strengths of a large number of universities, other higher educational institutions, national laboratories and even R&D laboratories in the private sector and works towards the growth of important emerging areas in S&T and their application to economic and societal development, wherever possible. For taking the benefits of scientific knowledge to the society at large, DST interacts with socio-economic ministries and these ministries are increasingly seeking advice and active participation of DST in deciding upon the S&T inputs required for their programmes and activities.

Apart from this continuing process of promoting new areas, networking institutions, coordinating multi-institutional projects and establishing specific infrastructure for S&T, DST aids a number of high-quality autonomous scientific research institutions specializing in different areas -- ranging from medical research, materials and earth sciences to astronomy.

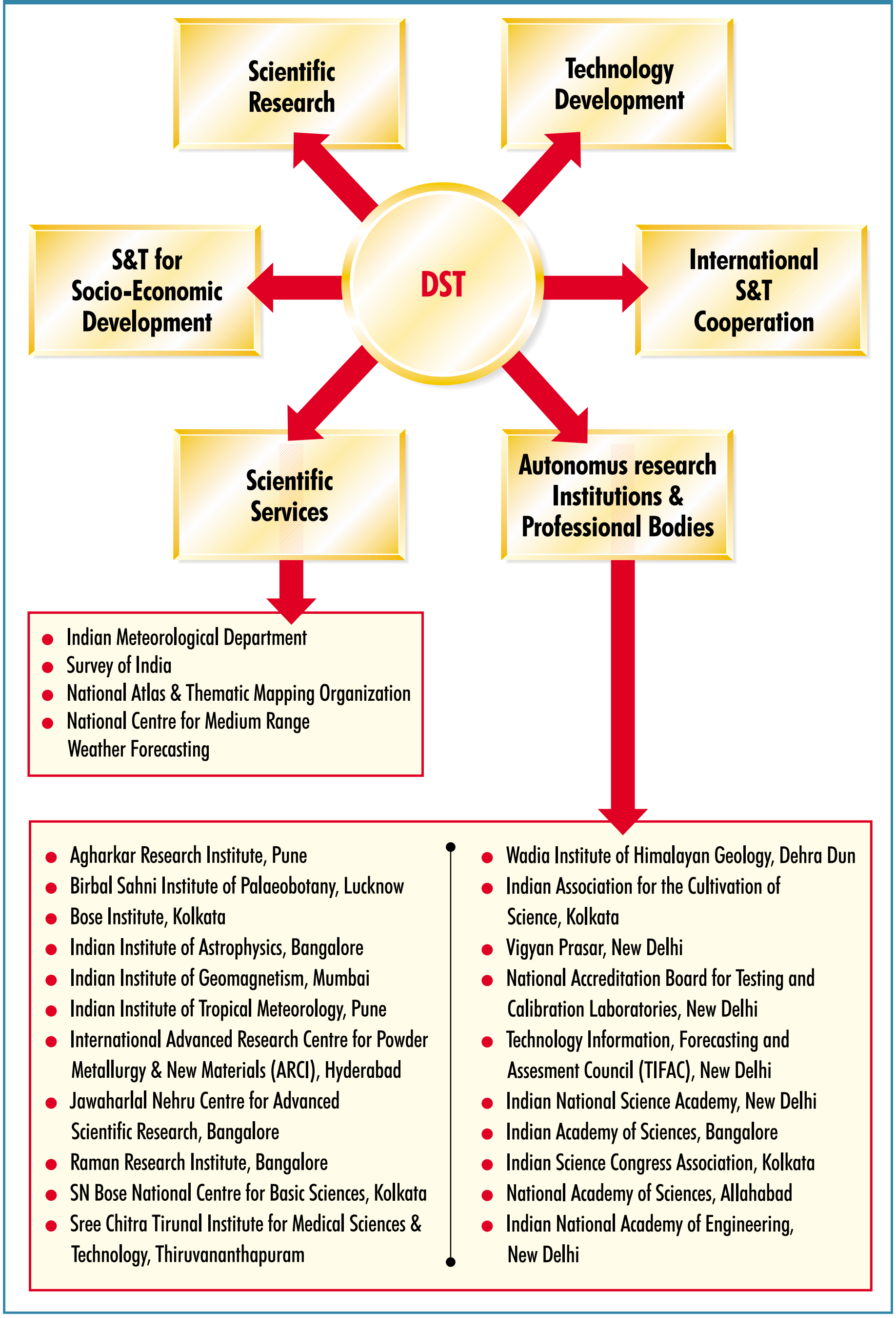
Another major responsibility of DST, often overlooked, is to provide scientific services to the country at large. The India Meteorological Department (IMD), an organization of DST, regularly provides meteorological services to the country as well as to the world community. The World Meteorological Organization (WMO) has recognized IMD as one of the Regional Centres for meteorology-related services. Mapping- and cartography-related services are provided by the Survey of India and the National Atlas & Thematic Mapping Organization (NATMO).

The DST has also been assigned major responsibilities towards development and application of indigenous technology. For this purpose, a fund for Technology Development and Application has been generated and, to administer the fund, the Government has constituted the Technology Development Board in 1996.

The DST's mandate, role and responsibilities are thus truly multi-dimensional and extremely dynamic in nature. No wonder, extremely flexible and multi-pronged approaches and instruments have been used by DST in achieving its goals and fulfilling its national responsibilities.

A brief resume of the activities and achievements of DST are given below which reflect the wide canvas on which it operates.

THE REACH OF DST'S ACTIVITIES



SCIENTIFIC RESEARCH

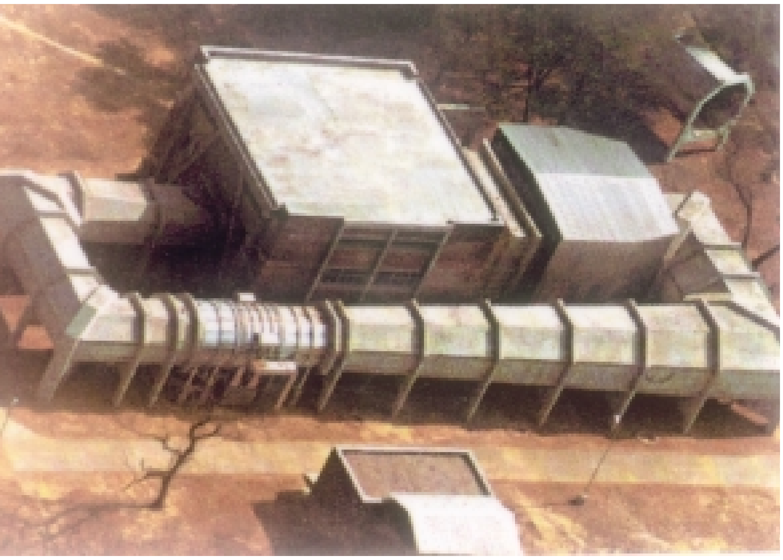
Scientific research, as a source of human knowledge, forms an integral part of the cultural process. Historically, it has been nurtured by all civilized societies primarily for its cultural value. In contemporary society, however, promotion and pursuance of scientific research have also become the means of survival and an economic necessity. Human society in coming years is going to be increasingly technology-driven. Technology rides on the back of basic R&D in Science and Engineering and, hence, scientific R&D will be increasingly a driving force in the health, wealth and strength in the coming decades. With the globalization of economies, it will be impossible to guard our economic sovereignty unless we are able to compete technologically. But, it is innovative science which provides insights and approaches to development and helps leapfrog rather than follow the trodden path and provides the basis and understanding of technology. It is, therefore, of utmost importance to create a strong edifice of basic research in science and engineering to guarantee the long-term technological competitiveness of India.

The DST promotes R&D in the emerging and frontier areas of science and engineering through the Science & Engineering Research Council (SERC). The SERC is an apex body consisting of eminent scientists from universities, national laboratories and industry. The SERC provides support for meeting the research needs of individual scientists, establishment of core-groups and centres of excellence and setting up of major national research facilities. In addition, the Council supports training

programmes for young scientists, organization of summer / winter schools and so on.

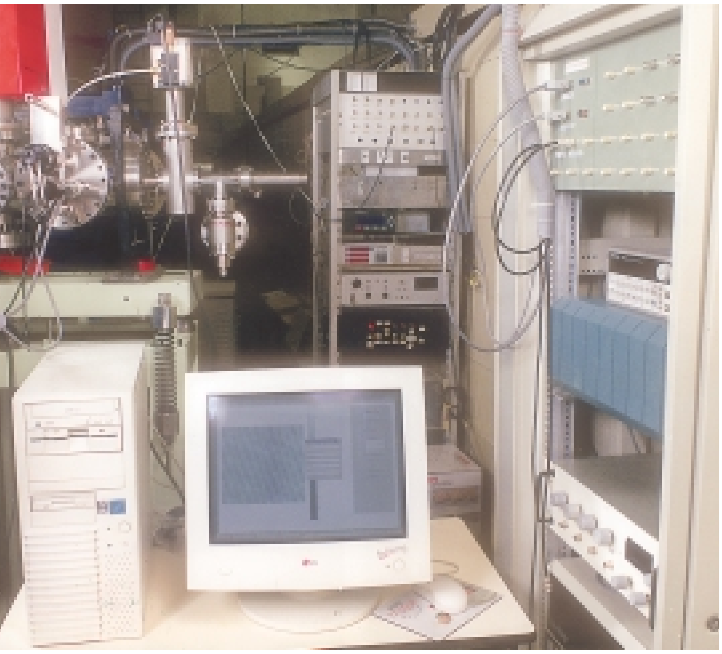
Through the SERC initiatives, it has been possible to promote and strengthen research in a wide variety of areas like structural and reproductive biology, plant physiology genetic engineering and biotechnology, neurobiology, animal behaviour, laser spectroscopy, condensed matter physics, solid state chemistry, organic chemistry, technical acoustics, robotics and manufacturing, geotechnical engineering, climate research etc. Several major research projects, facilities and centres of excellence have also been established recently—National Centre for Computational Fluid Dynamics at Indian Institute of Technology (IIT), Chennai; Facility for Technical Acoustics at Indian Institute of Science (IISc), Bangalore; Facility for Laser Scanning Confocal Microscope at Centre for Cellular and Molecular Biology (CCMB), Hyderabad, and Banaras Hindu University (BHU), Varanasi; development of high resolution photoelectron spectrometer at IISc, Bangalore; National Single Crystal X-Ray Diffractometer Facility at University of Hyderabad; development of PECVD based process for amorphous silicon solar cells at IACS, Kolkata; a cross circuit wind tunnel facility at IIT, Kanpur ; a geo-technical centrifuge facility at IIT, Mumbai ; Nonlinear Dynamics Unit at Bharathidasan University, Tiruchirapalli; development of an on-line UHV-STM facility at the Nuclear Science Centre, New Delhi; and single crystal X-ray diffractometer facility for Macromolecular Crystallography at All India Institute of Medical Sciences (AIIMS), New Delhi.

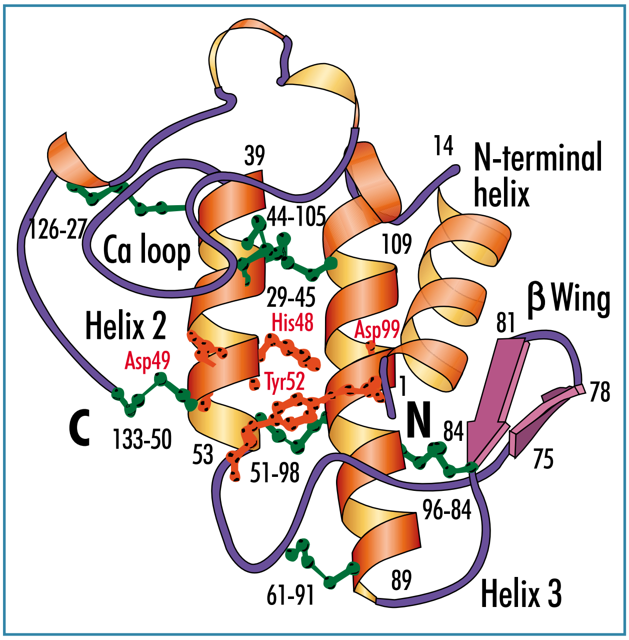
Top: A cross-circuit wind tunnel facility at IIT, Kanpur ;
Bottom: A geo-technical centrifuge facility at IIT, Mumbai, the main assembly.

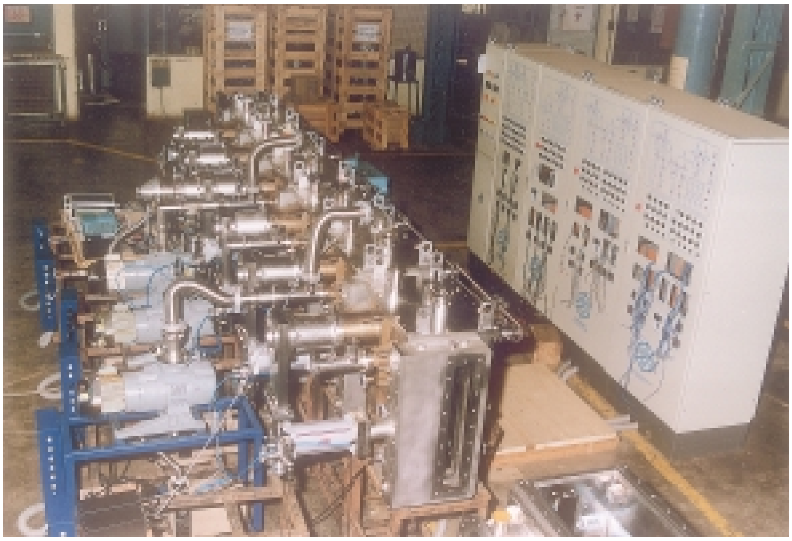




Under Earth System Sciences, the programmes taken up are -- the Monsoon and Tropical Climate (MONTCLIM) Programme, Indian Climate Research Programme (ICRP) and Bay of Bengal and Monsoon Experiment (BOBMEX). Three Automatic Weather Stations (AWS) and one permanent mountain meteorological observatory at *Gangotri* glacier have been established. Under the Seismicity Programme, good infrastructure has been created at various identified locations and laboratory facilities have been established in different institutions. New geographical areas like, the Delhi region, Peninsular shield and the Bihar plains, have also been taken up for carrying out integrated studies. Modern seismological observatories have been set up at a few selected locations in the North East region. A programme on microzonation of mega cities has also been initiated. A national initiative is being launched to strengthen the seismic network in the country.







Top: Online UHV- Stm facility at the Nuclear Science Centre, New Delhi;
Top right: A Crystal structure determined at the Single Crystal Diffractometer Facility at AIIMS, New Delhi;
Right: A view of the production plant for a-Si solar modules designed and fabricated indigenously at IACS, Kolkata.

Recognizing the importance of R&D for the growth of the Indian Drug Industry, a major programme on Drugs and Pharmaceuticals has been launched. The DST selectively supports collaborative projects between industry and research institute/university. Some important projects have been: characterization of crystals of biological macromolecules of medicinal and industrial importance, strengthening of pharmacological testing facilities and identification of immunomodulating potential of products and extracts of natural origin.

Efforts to encourage young scientists have been intensified. A Fast Track Scheme for supporting research projects from young scientists below the age of 35 years has been started. A new programme of *Swarnajayanti* Fellowships has been launched to mark the Golden Jubilee of Independence. This fellowship is awarded to exceptionally creative young scientists in the age group of 30-40 years to pursue world-class research. About 20 persons have been given these prestigious fellowships after a rigorous selection. Another important initiative is the *Kishore Vaigyanik Protsahan Yojana* (KVPY) which has been launched with the active support of IISc, Bangalore; IIT, Mumbai; AIIMS, New Delhi; and PGIMER, Chandigarh. This is to encourage young students, right from the school and undergraduate level, to take up research as a career. A total of 120 students received these scholarships in 2001. Young

Scientists (under the age of 35) are provided better opportunities of training in laboratories abroad in selected areas of science and engineering for periods ranging 3 to 12 months (BOYSCAST Programme). An Integrated Science Olympiad Programme, covering Physics, Chemistry and Biology, is currently on in collaboration with the DAE and the Ministry of Human Resource Development. Indian teams have been performing very well in the corresponding International Olympiads. A scheme has been floated to utilize the expertise of scientists retired from service to prepare monographs, books and treatises.

A scheme called 'Fund for Improvement of S&T Infrastructure in Universities and Other Higher Educational Institutions (FIST)' has been launched. It is meant to provide infrastructural facilities for basic research and nurture a congenial environment for promoting R&D in emerging areas and attracting fresh talent. On a competitive basis, the DST has so far identified 221 departments/laboratories for support under this scheme.

> THE NEW THING IN THE MODERN WORLD IS SCIENCE AND SCIENCE IS THE NEW HUMANISM.
>
> D.S. KOTHARI

The existing Regional Sophisticated Instrument Centres (RSICs)/Sophisticated instruments facilities (SIFs) located in various educational institutions and research organizations are continuing to serve the research needs for sophisticated analytical instruments such as ICP, WMR, EPR, Mass Spectrometer XRD, TEM and SEM among the scientists in the country. Several projects on development of instruments in the following areas were funded -- analytical, medical, environment monitoring and pollution control, food processing, testing and measuring, geo-scientific, agri-electronic, textiles, leather instrumentation and sensors.

A National Science & Technology Management Information System (NSTMIS) has been set up with the responsibility of collecting, collating, analysing and disseminating vital S&T information for decision-making at the national level. National surveys have been carried out to collect information on resources devoted to S&T activities in the country. As a result of such surveys, useful documents related to R&D statistics at the national level and in industry and a directory of extramural R&D projects have been brought out. These documents have been very well received by the science community, both in India and abroad.

Technology Development

While underlining the need for research in basic sciences, it is also necessary that R&D must have relevance for national priorities and goals. After all, this complementarity was envisioned in the Scientific Policy Resolution of 1958. Above all, research should be geared to stimulate economic growth and have a practical base. The urgent need to develop techniques that would assist in accelerating the pace of industrial growth cannot be ignored, for this has a direct bearing on the quality of life and economic well-being of the nation.

The DST has pursued its agenda of Technology Development through the Technology Development Board (TDB) and Technology Information, Forecasting and Assessment Council (TIFAC). A long-term Technology Forecasting exercise was conducted by TIFAC and Technology Vision 2020 documents have been brought out in 17 different areas.

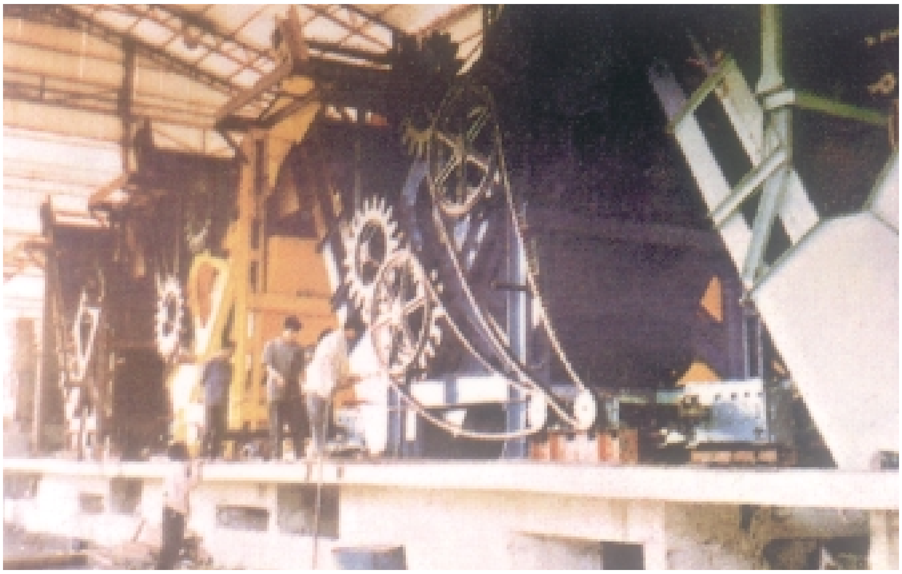
As a follow-up of Technology Vision 2020 documents, TIFAC has embarked on several important projects in the 'Mission Mode'. The 'Mission Mode' was considered necessary because of the overall complexity of technology proving and transfer, infrastructure support, inter-institutional linkages, development of market and orientation of government policies. It ensures that all critical

components fall in place in the end-to-end chain leading to the final product or goal.

Among these Technology Vision 2020 Mission Projects are : Bihar Agricultural Project; Eastern UP Agricultural Project; Kancheepuram Agricultural Project; Integrated Gasification Combined Cycle (IGCC) Project; and REACH. The Mission REACH (Relevance and Excellence in Achieving New Heights in Educational Institutions) is aimed at creating Centres of Excellence in selected departments of Science & Engineering Colleges at par with the best in the world to attract industries to solve targeted problems in a time-bound manner.

Among the earlier mission mode projects of TIFAC were: the Sugar Technology Mission; the Fly Ash Mission; and the Advanced Composite Mission.

The Sugar Technology Mission aims at technological upgradation of plants to accomplish cost-effectiveness of sugar production, improvement in plant deficiency, quality of sugar, and energy saving. Technology upgradation work has been undertaken in 30 sugar factories. New technologies which have been successfully implemented include Separate Clarification of Vacuum Filtrates, Use of Decanter Centrifuge, Low Pressure Extraction System and Thin Film Sulphur Burner for continuous generation of SO_2 to achieve satisfactory juice clarification parameters.





Top: Low Pressure Extraction System (LPE) for energy saving during sugarcane juice extraction
Bottom: Use of flyash bricks in World Bank office building at Trebeni, West Bengal

The Advanced Composite Mission successfully launched 20 projects, out of which six projects were completed successfully and various products were developed which included composite artificial limbs, FRP gear case etc. Several major users have become active partners recently and eight projects have been launched which have direct relevance to the Indian Railways.

The Fly Ash Mission made significant impact on fly ash utilization, its safe disposal and services associated with its management. The Fly Ash Mission has so far undertaken 55 projects, of which 35 have been completed. The completed projects have had significant multiplier effects. Due to increased awareness, there has been a considerable increase in fly ash utilization.

Under the Home Grown Technology (HGT) Programme, several companies have successfully



The first industry sponsored technology 'Membrane Oxygenerator' enters clinical trials prior to commercial production.

developed pilot-scale technologies and started commercial production immediately after the HGT phase. These relate to natural dyes, rapid diagnostic kits for cattle and poultry, farm animals and domestic fowls, bio-adhesive for sutureless surgery. Under the Technopreneur Promotion Programme (TePP) started jointly by DST, DSIR, and TIFAC to tap the vast innovative potential of Indian innovators, several projects have been supported which include development of zeolite based Catalytic Converter, next generation Membrane Oxygenerator etc.

A single-window Patent Facilitating Centre (PFC) has been set-up in TIFAC to provide comprehensive information related to patenting and intellectual property and to provide facilities to scientists and technologists on patents and, in general, to create awareness and understanding of this area. The Patent Facilitating Centre (PFC) has helped in filing over 72 patents. It has also helped in conducting numerous patent searches and has become a major focal-point for assistance to the scientific community on all issues related to Intellectual Property and Patenting.

As part of the IS-STAC mechanism, 12 Joint Technology Projects have been launched in collaboration with various socio-economic Ministries. Significant among them are development of Column Floatation Technology at Hindustan Zinc Limited (HZL) for Ore Benefaction and Pilot Enrichment Plant for Helium from Hydrothermal Sources at SINP, Kolkata, supported by DST with the Department of Mines and DAE, respectively.

The Government of India constituted the Technology Development Board (TDB) in September, 1996, to promote development and commercialization of indigenous technology and adaptation of imported technology for wider application. The TDB has concluded 84 agreements with commercial enterprises and three with other agencies till end of March 2001. The total cost of these projects was Rs.9,885 million including the TDB's commitment of Rs.3,581 million by way of loans, equity and grants. The sectors covered include health and medicine, chemicals, engineering, agriculture, and transport. The TDB has instituted a National Award for successful commercialization of an indigenous technology and an other award for the successful commercialization of a technology based product by a SSI unit. These awards are presented on the Technology Day, i.e. 11th May every year.

S&T FOR SOCIO-ECONOMIC DEVELOPMENT

S&T has established its viability in terms of products, processes and development models that have tremendous potential in changing the rural economy and addressing the problems of our rural people. A variety of technologies have been devel-

oped and replicated in both farm and non-farm sectors. The attempt has focused on artisan skills, upgradation of traditional technologies and developing women-friendly technologies. The approach adopted while implementing these rural programmes has been to involve voluntary organizations to ensure people's participation at various stages of planning, project formulation and implementation.

A number of schemes have been initiated and these relate to S&T for weaker sections, S&T for women and S&T application for rural development etc. Rural Technology Parks have been set up in the North-Eastern India. Need-based projects have been supported in the hilly regions. A number of projects have been sanctioned on sustainable development and utilization of natural and community resources and micro-enterprise development in the villages. Individual S&T-based projects in farm and non-farm sector, inland aquaculture, sustainable agriculture, and solar/biomass based energy devices/systems have been supported. Projects have been implemented in priority sectors such as post-harvest technologies, land-based activities, women's health, income generation activities, drudgery removal and rural engineering. Three Women Technology Parks have been set up at Dehra Dun, Manipal and Barmer. A National Award has also been instituted to recognize the contribution made by an individual/ organization for the benefit of women.

New programmes on Waste Recycling and Rehabilitation of Scavengers, Rag Pickers both in Urban and Semi-Urban Areas have been launched for management of garbage. These aim at recycling of waste and conversion of vegetable kitchen waste into compost through vermicomposting. The DST has also achieved a major breakthrough in the form of a project on food security by installing a fish aggregation device in the Andaman Islands for a tribal group.

The National Science & Technology Entrepreneurship Development Board (NSTEDB) aims at stimulating entrepreneurship among graduates in Science & Technology and diploma-holders in Engineering. It is intended to create job-generators rather than job-seekers. Under the Entrepreneurship Development Scheme, 24,000 students have been exposed to the concepts of entrepreneurship. A total of 371 Entrepreneurship Development Programmes (EDPs) and 60 Technology Based Entrepreneurship Development Programmes (TEDPs) have been sponsored by NSTEDB and 542 units have been established by their beneficiaries. 896 teachers/trainers have been trained in entrepreneurship development. A new programme called Technical Human Resource Development -- Skill Upgradation through Vocational Training has been initiated in association with the United Nations Development Programme (UNDP). The reach of STEP programme has been extended to new locations and a scheme on Technology Business Incubators (TBIs) has also been initiated during the IX Plan. The STEPs have so far promoted nearly 700 units generating an annual turnover of around Rs. 900 millions and generating employment for 5,000 persons. More than 100 new products and technologies have been developed by STEPs or STEP-promoted entrepreneurs. In addition, over 6,000 persons have been trained through various skill development programmes conducted by STEPs. Some of the newer programmes are National Facility for Science & Technology Based Entrepreneurial Innovation (Innovation Centre) and National Project for International Business Information & Research (International Business Centre).

All State Councils were supported for setting up and strengthening S&T structures and facilitating information exchange. Support was also initiated by State Councils for demonstration projects, application projects and S&T studies and surveys.

With a view to popularize S&T and stimulate scientific and technological temper among people, the National Council of Science & Technology Communication (NCSTC) has taken major initiatives. Among them are the *Bharat Jan Vigyan Jathas* (BJVJ) and a number of other initiatives aimed at reaching large number of people across the country. Four

National Children's Science Congresses (NCSCs) have been organized. A television serial *Kudratnama* was also telecast. A Blood Donation Project was also implemented. Video programmes on different scientific topics were also telecast. *Vigyan Prasar* has continued its efforts to promote and propagate scientific and rational outlook in society through *Vigyan Prasar Information System*, network of science clubs, development, production and demonstration of S&T software.

15 GIS Database Centres were set up as part of the National Resources Data Management System (NRDMS) Programme. Planning Atlas for some districts of Gujarat were prepared. Coordinated programmes in the areas of SAR Interferometer ground water modeling, coastal zone management and conservation and bio-geo-database and ecological modeling have been initiated.

> THE ULTERIOR END OF SCIENCE IS SEARCH FOR TRUTHS OF NATURE AND OF THE UNIVERSE, AND TRUTH ALWAYS BUILDS AND INTEGRATES.
>
> D.N. WADIA

International S&T Cooperation

The DST has the nodal responsibility to plan, negotiate and coordinate the implementation of agreements with various countries and international bodies. The DST's International S&T Cooperation Programmes focused on well-coordinated activities with the erstwhile Soviet Union and USA and also other developed and developing countries. Activities with Russia continue under the Integrated Long Term Programme (ILTP) of cooperation in Science & Technology. Under ILTP, an Indo-Russian Research Centre in Advanced Computing (CDAC-ICAD) was established at Moscow. An Indo-US S&T Forum for bilateral cooperation in Science & Technology has been set up. India's share of funds would be about Rs.35 millions per year which will be a matching fund equal to the approved earning from the endowment fund of Rs.320 millions received from the US side. The DST-NSF programmes also promote cooperative research as part of the Indo-US Programmes. The Indo-French Centre for Promotion of Advanced Scientific Research has been actively supporting a large number of collaborative research projects in identified thrust areas. Under the Indo-German Programme, technology-oriented projects have been supported on Surface Engineering of Components, Steel for Automobiles, Special Plastics Processing and Pharmaceuticals Development. A DST-DAAD Project-based Personnel Exchange Programme has been initiated in 1999.

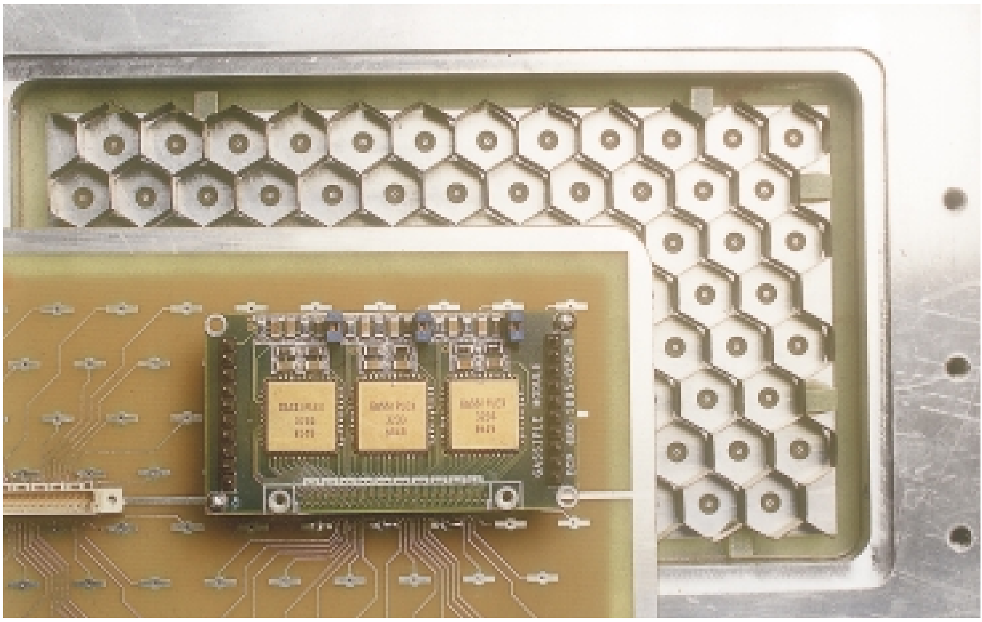
A scheme to depute young scientists to participate in a meeting of Nobel Laureates in Germany has also been started in 2001. Under the Indo-UK programme, joint projects have been implemented in fields like Advanced Materials & Manufacturing Technologies and Information Technology. The India-Japan Programmes have been implemented under two arrangements, the Inter-Governmental Joint Committee and the India-Japan Science Council. Indian scientists conducted more than a dozen fundamental experiments at Spring-8 in Harima and at the Photon Factory in Tsukuba. Japanese expertise was also used in characterization of the Hanle site in Ladakh for installation of a 2 m telescope. A 14 GFLOP computer has been established in Indian Institute of Astrophysics (IIA), Bangalore, for N-body simulations. A new programme for accessing facilities at the Centre for Magnetic Resonance (CERM) has been started under the Indo-Italian Programmes in Florence. Another project involves clinical trials with a cost-effective Hungarian drug for Bone Marrow Transplantation in cancer patients.

S&T Cooperation with Developing Countries (STPCDC) has been continued through exchange

visits, joint seminars and workshops, training programmes, joint R&D programmes, and joint state-of-the-art reports. Programmes promoting S&T cooperation among SAARC and BIMSTEC countries have also been implemented. Support to NAM S&T centre has continued. New agreements on Science & Technology cooperation have been concluded with Myanmar, Bulgaria, Malaysia, Oman, Yemen and Syria as well as with Bangladesh, Vietnam, Sri Lanka, Cuba, Mexico, Tunisia and China.

Agreements have also been concluded with the Third World Academy of Sciences (TWAS) and the International Centre for Theoretical Physics (ICTP).

Two major International Collaborative Projects for experiments at CERN, Geneva, have received joint funding from DST and DAE. In the first, namely, the India-CMS project, the Indian scientists will contribute to the building of the CMS detector and participate in subsequent tests of the Standard Model and search for new particles in proton-proton collisions at the Large Hadron Collider. In the second, India-ALICE project, the Indian scientists will participate in the ALICE experiment at LHC and look for the existence of quark-gluon plasma.



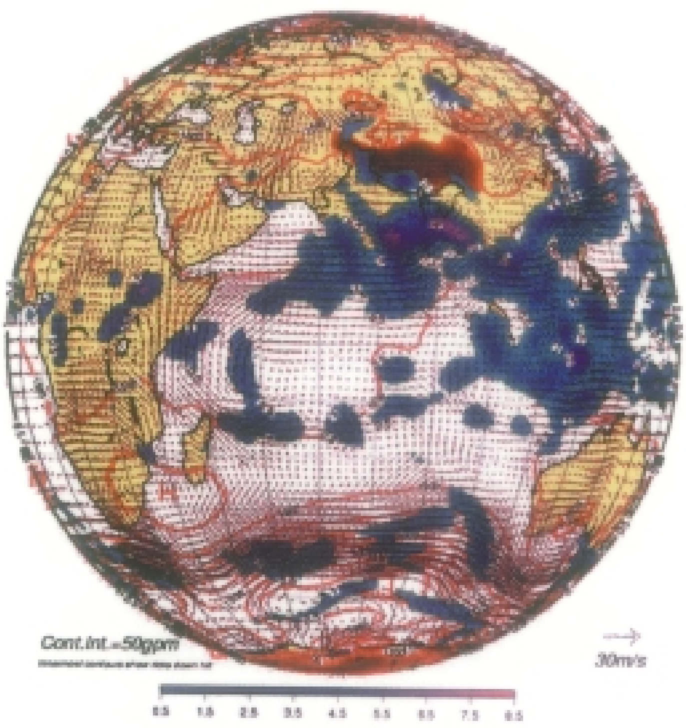
Towards the Photon Multiplicity Detector (PMD) for Alice Experiment: A 96- cell honeycomb prototype detector with printed circuit boards and gassiplex chips separately shown (before assembly).

Scientific Services

Despite all the advances in the field of S&T, the common man's inherent vulnerability to natural calamities is a constant threat. Since control is not possible, R&D focus on accurate and sensitive data collection on which to base warnings and forecasts. Not only can this information benefit the farming and fishing communities but it also goes a long way in mitigating the impact of natural disasters and mobilizing relief measures.

Scientific services in the areas of meteorology, survey and mapping have been provided by DST to the user agencies through the India Meteorological Department , Survey of India , National Atlas and Thematic Mapping Organization (NATMO) and the National Centre for Medium Range Weather Forecasting (NCMRWF). The IMD has also carried on research work in fields such as ozone in tropics, agricultural meteorology, use of monsoon, telecommunications etc. and also provided specialized services in the form of meteorological forecasts for different types of users through a network. Upgradation of the existing cyclone detection network of IMD through deployment of Doppler radars is in progress. The upgraded IMPDS system for INSAT-2E reception has been fully commissioned and installation of the earth station is in progress. The network of seismological observatories has been upgraded to become a part of the Global Network. Efforts are being made to strengthen the seismological network and infrastructure in the country to ensure better seismological observations. In the area of weather forecasting, a supercomputer has been commissioned and NCMRWF has been set up for development of sophisticated numerical

weather prediction models for medium range weather forecasting, crop-weather relationship patterns etc. The NCMRWF has acquired a new Cray SVI computer system, which has been commissioned in June, 2001. Meanwhile, a low-end computer system has been installed to ensure uninterrupted production of weather forecasts. The functioning of the existing AMFUs has been consolidated and some



Earth view chart for a typical case of 14th June 2001 showing 24 hour forecast of wind at 850 hPa of total precipitation (cm) from the NCMRWF T80 forcast system. A depression is seen over Bihar and West Bengal. Contours of Geopotential height are shown in red colour.

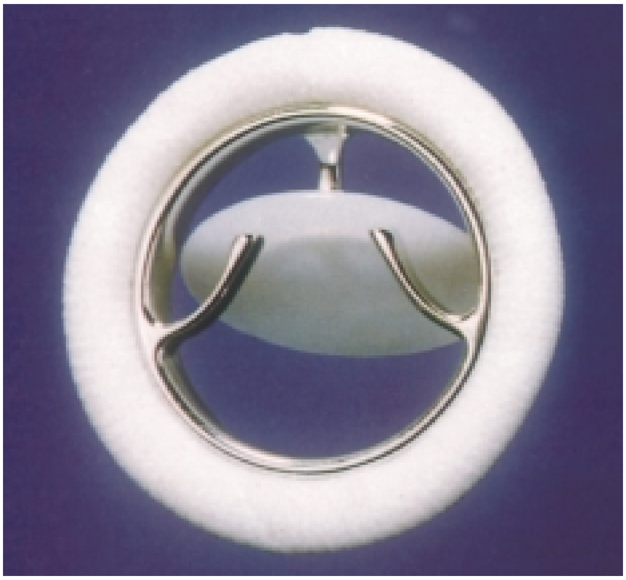
more AMFUs are to be set up shortly. In view of the modern technologies and the multi-disciplinary approach being adopted in various planning processes, the Survey of India is expected to supply multifarious scientific data and large-scale maps at frequent intervals. The Survey of India has introduced digital cartography techniques in its circles and units to create Digital Cartographic Data Bases (DCDBs) from the topographical maps. Efforts are on to launch major programmes on management of natural disasters through S&T inputs.

Autonomous Research Institutions

The autonomous research institutions of DST are engaged in R&D in emerging areas of astronomy and astrophysics, palaeobotany, Himalayan geology, geomagnetism, microbiology, modern biology, medical sciences and technology and several other fields. These institutions have also set up major national facilities to be utilized by the scientific community and have contributed significantly to research at the national and international level. The subsequent paragraphs indicate some of the research activities undertaken in the recent past.

The Agharkar Research Institute has carried on research activities with emphasis on both applied and basic aspects of research. A foliar spray that enhances crop yield has been transferred to Sainath Agro-Vet Industries, Lopergaon which markets the product under the trade name BIOFERT. In the important area of waste water treatment using microorganisms, a laboratory-scale process for microbial detoxification of cyanide and metal-cyanide complexes has been developed and bioremediation of caprolactam from nylon industries has been achieved. In basic research, a molecular marker for leaf rust resistance gene LR 28 in wheat has been identified and a patent has been filed jointly with the National Chemical Laboratory, Pune.

Nanostructred semiconductor and CMR materials and devices have been developed at IACS, Kolkata. Sree Chitra Tirunal Institute for Medical Science and Technology at Thiruvananthapuram has made outstanding contributions in the field of biomedical technology and medical services and a number of biomedical products (blood banks, heart valves, vascular grafts, oxygenerator incubators for babies etc) have been developed and marketed. It has recently started an Epilepsy Care Centre with surgical facilities -- the only one of its kind in India. A transgenic yellow stem borer (YSB)-resistant



The Chitra Heart Valve fabricated at the Sree Chitra Tirunal Institute for Medical Science & Technology, Thiruvananthapuram.

indica rice, having a high level of expressed toxin, has been developed at the Bose Institute, Kolkata. Tomato and banana plants have been regenerated by tissue culture and micropropagation.

The Jawaharlal Nehru Centre for Advanced Scientific Research Centre, Bangalore, has established an Advanced Materials Research Laboratory (AMRL) and has initiated a programme to provide summer fellowship opportunities to young scientists and students to expose them to advances in scientific research in the country.

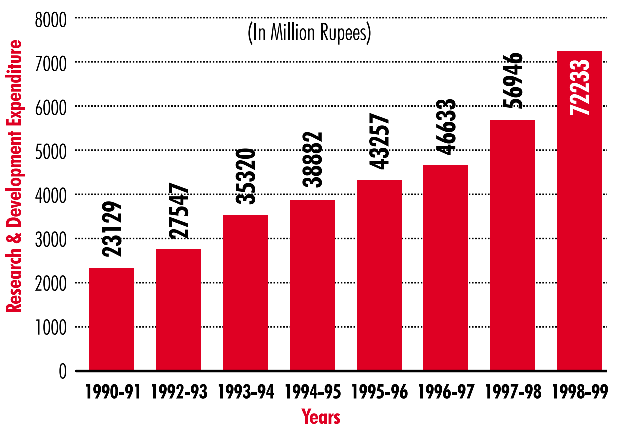
The Raman Research Institute, Bangalore, has continued with its research in astronomy, instrumentation for astronomy and liquid crystals and soft condensed matter physics. The IIA, Bangalore has established the world's highest observatory for optical and infrared astronomy in the Himalaya. *Vigyan Prasar* has been engaged in development of a variety of softwares for S&T communication, science popularization and national campaigns around special events such as the total solar eclipses of 1995 and 1999. The Indian Institute of Tropical Meteorology, Pune, has developed forecast models based on different statistical techniques and by using different global models for the Indian Monsoon Rainfall. The Birbal Sahni Institute of Palaeobotany, Lucknow, has been conducting research in botanical and geological aspects of plant fossils which have proved effective in tracing the antiquity of early life, evolutionary patterns of floras, vegetation dynamics, high resolution biostratigraphy, exploration of fossil fuels, palaeoenvironments and palaeoclimatic interpretations. The Indian Institute of Geomagnetism, Mumbai, has concentrated its programmes on upper atmospheric studies and solid state geomagnetism. The Wadia Institute of Himalayan Geology, Dehra Dun, has taken up collaborative programmes on seismic hazards with universities and organizations abroad. The International Advanced Centre For Powder Metallurgy and New Materials, Hyderabad, has sustained its focus on developing a strong technology base and is working towards becoming technologically self-sufficient in the areas of powder metallurgy, ceramics and surface engineering. The Centre has successfully transferred a number of technologies and has brought into vogue a unique technology transfer culture, which involves the technology-receiver from the germination stage.

The National Accreditation Board for Laboratories (NABL) is a programme of national importance aimed at providing official recognition to testing and calibration laboratories within the country. A Quality Manual for the Accreditation Body has been prepared. 101 laboratories have been accredited during the year 2001. The NABL has finalized the 'Specific Criteria Documents' for accreditation of laboratories. The NABL aims to bring about competitiveness in the industry and improve export potential of indigenously manufactured products by encouraging the concerned parties to meet international quality norms.

The DST has been providing encouragement and financial support to the leading scientific academies of the country, which are autonomous and have their own specific goals and activities.

Some Important Data on S&T (including Education) Scenario

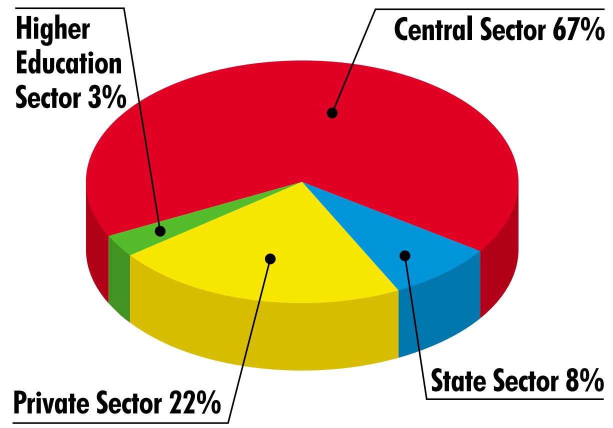
EXPENDITURE ON R&D BY MAJOR SCIENTIFIC AGENCIES UNDER THE CENTRAL GOVT.



(Source: Department of Science and Technology)

NATIONAL EXPENDITURE ON R&D BY SECTOR

(In Million Rupees-1999-2000)



(Source: Department of Science and Technology)

Sector-wise plan and non-plan budget estimates (Revenue Account) for education by Central and State Governments

Sector	PLAN			NON-PLAN			TOTAL		
	States	Central	Total	States	Central	Total	States	Central	Total
Elementary Education	21432.5	22624.8	44057.3	138787.1	9.8	138796.9	160219.6	22634.6	182854.2
Secondary Education	13250.6	3772.1	17022.7	91654.8	3322.7	94977.5	104905.4	7094.8	112000.2
Adult Education	1125.3	2236.0	3361.3	378.1	26.6	404.7	1503.4	2267.6	3766.0
University & Other Higher Education	3005.8	2380.6	5386.4	31893.6	4846.5	36740.1	34899.4	7227.1	42126.5
Technical Education	3801.4	2538.9	6340.3	5975.1	2323.8	8298.9	9776.5	4862.7	14639.2
Physical Education	140.7	6.0	146.7	218.1	3.0	221.1	358.8	9.0	367.8
General	1584.4	137.8	1722.2	6070.0	250.7	6320.7	7654.4	388.5	8042.9
Language Development	242.7	164.0	406.7	948.6	140.9	1089.5	1191.3	304.9	1496.2
Total	44583.4	33860.2	78443.6	275925.4	10924.0	286849.4	320508.8	44789.2	365293.0

(Source: Department of Science & Technology, GOI)

Expenditure on Education in Relation to GNP

Particulars	1990-91	1992-93	1993-94	1994-95	1995-96	1996-97
GNP at market prices	5279890.0	6935250.0	8648720.0	9331200.0	1009683.0 +	10857100.0 *
Education Expenditure	207613.3	253027.0	285985.8 +	328753.6	392994.1	437226.6
Central Government	24204.5	28546.8	36113.9	38272.5 *	54426.7	63608.7
State Governments	183408.8	224480.2	249871.9	290481.1	338567.4	373617.9
(Education/GNP) in %	39.0	36.0	33.1	35.2	38.9	40.3

(Source: Department of Science & Technology)

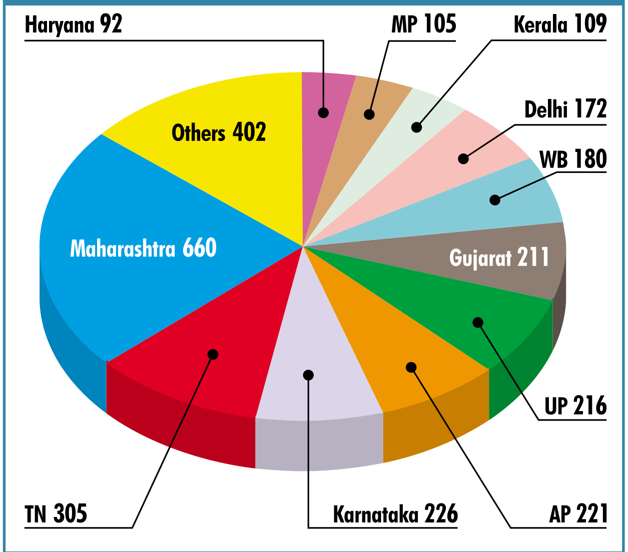
Symbols: + Revised Estimates; *. Budget Estimates

Note: 1. The Centre and State Education Department budget is total of the Revenue, Capital, loans and advances and other Departments for the respective years.;

2. Total expenditure on Education includes Expenditure by the Education Department and Other Departments, and advances where other Departments Expenditure also includes expenditure for training (formal/informal) but exclude the budget of Railways and Posts and Telegraphs.

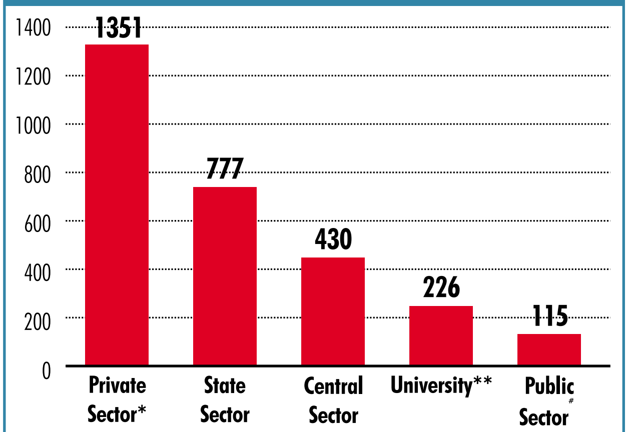
3. States include States and Union Territories.

STATE-WISE NUMBER OF R&D INSTITUTIONS



(Source: Department of Science & Technology, GOI)

SECTOR-WISE NUMBER OF R&D INSTITUTIONS

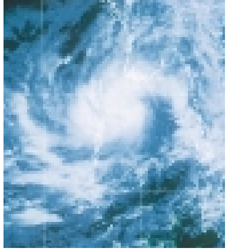


** University includes deemed universities and institutes of national importance

Public includes only in-house Research & Development units of Central Public Sector Undertakings

* Private includes in-house Research and Development units of private sector industry and scientific and Industrial Research recognised by Department of Scientific and Industrial Research

(Source: Department of Science & Technology, GOI)



CHAPTER XXIX

Atomic Energy in India

India's Atomic Energy programme has been a mission-oriented comprehensive programme with a long-term focus. From its inception the guiding principle of this programme has been self-reliance through the utilization of domestic mineral resources, and building up capability to face possible restrictions in international technology and the exchange of resources. The events of the last 50 years have, in fact, validated this approach.

The Department of Atomic Energy (DAE) in India is today a broad-based multidisciplinary organization incorporating basic and applied research, technology development and their translation into industrial application, as closely linked activities. As a result, India today builds its own thermal reactors and associated nuclear fuel cycle facilities and is well poised to march on to the second and third stages of its planned programme involving fast breeder and thorium utilization technologies respectively. This effort is expected to provide a significant long-term solution to India's crucial electricity needs to support its overall development.

The Role of Nuclear Power

There is a well established link between per capita electricity consumption and human development. The installed electricity generation capacity in the country is quite impressive and gross electricity generated during the year 2000-2001 was about 500,000 million units. In absolute terms, this is a large figure, but when looked at on a per capita basis, this is far below the world average. To meet our large electricity production needs, we have to tap all energy resources available to us. While coal-fired thermal power plants, apart from hydro, would remain the mainstay for our electricity production for quite some time, we would need to supplement them with sizeable additional resources to assure long-term energy-security as well as environmental protection. In this energy mix, nuclear power has an important role to play in the coming years.

The Indian uranium reserves are modest and cannot make an overly significant contribution to electricity requirements, if this uranium is used once in a nuclear reactor and then disposed of as waste. However, with a carefully planned programme, the available uranium can be used to harness the energy contained in non-fissile thorium, of which India possesses about 30 per cent of the world's reserves. The first stage of this programme involves using the indigenous uranium in Pressurised Heavy Water Reactors (PHWRs), which produce not only energy but also fissile plutonium. In the second stage, by reprocessing the spent nuclear fuel and using the recovered plutonium in Fast Breeder Reactors (FBR), the non-fissile depleted uranium and thorium can breed additional fissile nuclear fuel plutonium and uranium-233 respectively. In the third stage, thorium and uranium-233 based nuclear reactors can meet India's long-term energy requirements. Sustainable development of the country's economy requires nuclear energy, and sustainable development of nuclear energy requires closing the nuclear fuel cycle with thorium utilization.

Indian concerns and priorities are, thus, quite unique. For its long-term energy security India has

no option but to deploy nuclear power according to a strategy precisely tuned to its needs and resources.

Evolution of the Indian Nuclear Programme

Homi Jehangir Bhabha formulated this strategy nearly 40 years ago, when India possessed hardly any infrastructure to support the nascent nuclear technology. The first Prime Minister of India, Jawaharlal Nehru, helped Bhabha lay the foundations of the Indian atomic energy programme, with self-reliance as the motto. Accordingly, a large R&D establishment, named Atomic Energy Establishment, Trombay, was progressively set up. This was renamed the Bhabha Atomic Research Centre (BARC), after India tragically lost Bhabha in an air crash in 1966. It incorporates research reactors, basic facilities for nuclear research, supporting infrastructure, and trained humanpower in all disciplines dealing with nuclear energy.

The Indian nuclear power programme commenced in 1969 with the building of the twin reactor units of the Tarapur Atomic Power Station (TAPS), employing Boiling Water Reactors (BWRs), with American assistance. The reasons for this choice lay in favourable performance guarantees for these reactors, and the need to gain experience quickly in running nuclear power plants.

The construction of the first two Indian PHWRs, RAPS-1 and RAPS-2, was a joint venture project with Canada. In parallel, the DAE set up facilities for fabrication of fuel, zirconium alloy components, manufacture of precision reactor components, and for production of heavy water. The import content of RAPS-1 was 45 per cent and half of its first core fuel charge was imported. Commercial operation of RAPS-1 commenced in December, 1973. In the year 1974, India conducted the peaceful nuclear experiment at Pokhran. The Canadian support was summarily withdrawn while RAPS-2 was still under construction. France too, followed suit by refusing to supply fuel for the Fast Breeder Test Reactor (FBTR) which was then under construction with French cooperation. The USA expressed its inability to continue fulfilling its contractual obligations to supply fuel for TAPS. The era of technology control regimes had begun for the Indian nuclear programme.

Coping with the Pokhran-I Fall-out

The abrupt withdrawal of foreign technical co-operation and supplies following the Peaceful Nuclear Explosion Experiment of 1974, could have caused a serious setback to the Indian nuclear programme. This did not happen on account of the nation's determination to face the challenges head-on with the help of the R&D infrastructure already created to develop self-reliance, and the support of Indian industry. India's stakes lay not only in the continuation of the ongoing

FBTR at Kalpakkam.



activities without external help, but also in the pursuit of the originally stipulated long-term strategies.

To cut a long story short, although delays were caused in some ongoing projects, the embargoes spurred the growth of indigenous capability for developing substitutes for the denied products, technologies and knowhow. RAPS-2 started commercial operation in 1981; FBTR went critical in 1985, using indigenously made plutonium-uranium mixed carbide fuel; and India developed a plutonium-uranium mixed oxide fuel, as well as the facilities for its industrial scale production, as an alternative to the enriched uranium based fuel for TAPS. India has not looked back since, and has continued to proceed on its chosen path without depending on external help.

The Present and the Future

The table on the right summarizes the present status of and future plans for nuclear power in India. The designs of new reactors have progressively evolved to incorporate advanced features to further improve safety, reliability and economics. The country has successfully developed technologies for in-service inspection, maintenance and refurbishment of older plants. As India gains experience and masters various aspects of nuclear technology, the performance of its nuclear plants continues to improve. The average capacity factor of Indian plants in 1995-96 was 60 per cent and it has risen to 82.5 per cent during 2000-2001. So far they have produced more than 165 billion units of electricity.

Two 500 MWe PHWRs, fully designed and developed in India, are under construction at Tarapur. In parallel, to further accelerate the growth of nuclear power, plans are being considered to build a few light water reactor based plants as an additionality, with foreign collaboration. The deal with the Russian Federation for setting up two 1,000 MWe units at Kundankulam is a step in this direction. Pre-project activities for setting up these units have commenced and DAE expects to start construction later this year. The two programmes of light water reactor and the indigenous self-reliant three-stage PHWRs, run as parallel programmes.

Nuclear Power Plants: Present Status and Future Plans

	MWe
Plants under operation	
14 reactors at 6 sites-- Tarapur, Rawatbhata, Kalpakkam Narora, Kakrapar and Kaiga	2,720
Plants under construction	
2x500 PHWR at Tarapur	1,000
Plants likely to commence in the current financial year	
2x220 PHWR 2x1000 VVER 1x500 PFBR	2,940
Future plans	
2x220 PHWR 4x500 PFBR 10x500 PHWR 6x1000 LWR	13,440
Total:	20,100

The Nuclear Power Corporation of India Limited (NPCIL) has gained considerable experience and confidence in plant life management, after many complex repair and rehabilitation jobs. Its nuclear power reactor maintenance capability is now on par with that of advanced countries. The intricate job of *en masse* replacement of coolant channel assemblies in the RAPS-2 reactor was successfully completed by employing indigenously developed technology well ahead of schedule and with minimum consumption of man-rem. The technology for tackling the OPRD (Over Pressure Relief Device) problem of the RAPS-1 leak was evolved and demonstrated and the repair work carried out successfully. From RAPS-2 onwards, improved coolant channel material and modified channel design have been adopted for longer life of the coolant channel.

Nuclear Fuel Cycle

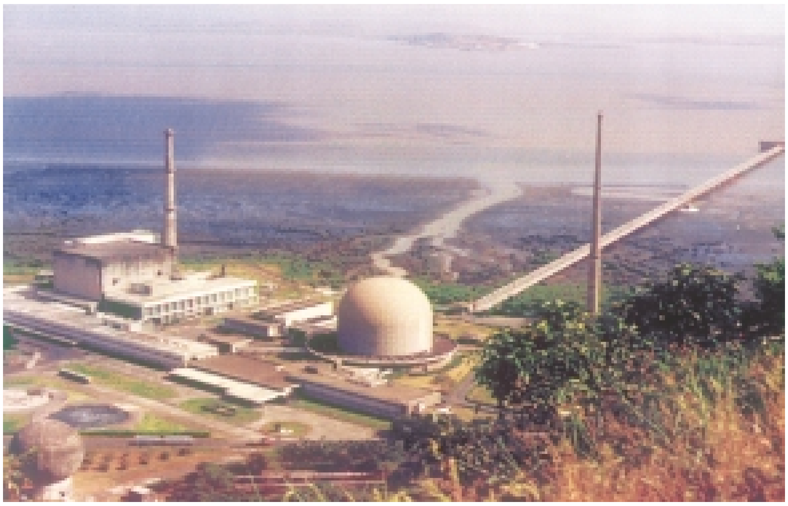
India has acquired a comprehensive capability in design and operation of associated plants/facilities (apart from reactors) covering the entire fuel

cycle, starting from mining, milling and concentration of ore, through fabrication of fuel and production of heavy water to reprocessing and management of waste. Today, heavy water plants are operating with high efficiency and with a good safety record in the processes and technologies based on hydrogen sulphide-water exchange and ammonia-hydrogen exchange. This has enabled India to export modest quantities of heavy water after meeting its domestic needs. Full-scale heavy water upgrading plants based on the electrolytic and vacuum distillation process are also operational. The focus at present is on implementing energy conservation measures so as to reduce the cost of production of heavy water.

Ensuring a continuous supply of reliable qualified fuel for the reactors is vital for maintaining a nuclear power programme. Fabrication of fuel for nuclear reactors is a complex technology demanding high level of competence in process engineering and technology, extractive and physical metallurgy, materials and manufacturing technology, modern quality control and inspection based on NDT techniques. During the last four decades, a wide variety of metallic, ceramic and dispersion fuels have been developed and fabricated on an industrial scale at the BARC and at the Nuclear Fuel Complex (NFC). Zircaloy clad, high-density natural uranium oxide 'pellet -pins', is the fuel for the 220 MWe and 500 MWe PHWRs in India and these have been fabricated on an industrial scale at the NFC over the last two decades.

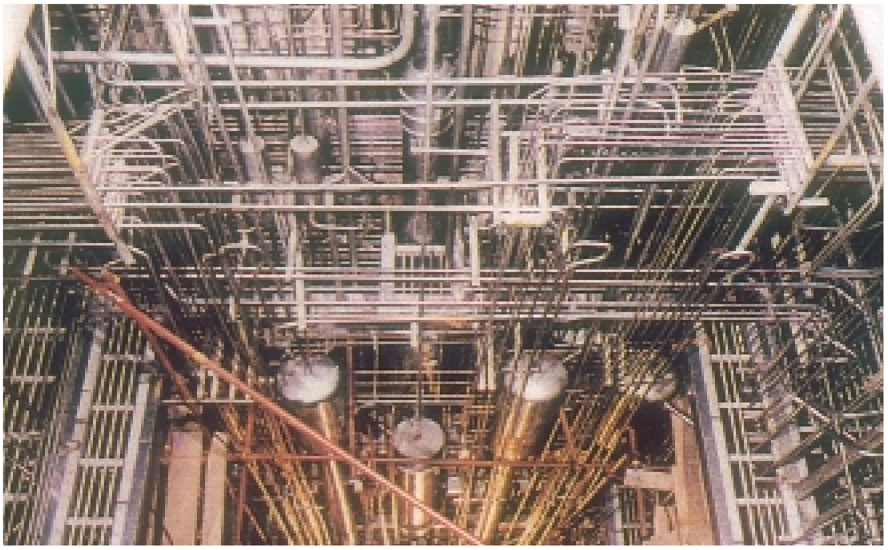
The nuclear energy resource profile of India calls for adoption of a closed cycle that involves reprocessing of spent fuel and the recycle of plutonium and uranium-233. India thus commenced development activities in fuel reprocessing technology from the inception of the nuclear programme and today has plants operating at Trombay, Tarapur and Kalpakkam. The first plant built at Trombay was designed with limited laboratory and pilot plant data, and with hot cell technology. However, the plant at Kalpakkam incorporates various innovations and new concepts based on experience gained from the operation of the Tarapur plant and R&D studies carried out in test facilities. In addition, we have separated uranium-233 from irradiated thorium rods and the radioactive





Top: Rajasthan Atomic Power Station (RAPS 3 & 4).
Bottom: Research Reactors DRUVA and CIRUS.

wastes generated at various stages of the nuclear fuel cycle are categorized as low-, intermediate- and high-level waste. State-of-art technologies have been developed and implemented for all three categories. A plant for immobilizing highly active waste in a glass matrix is operational in Tarapur. Based on this experience, new nuclear waste immobilization plants are being set up at Trombay and Kalpakkam. Vitrified waste is stored in a specially designed solid storage surveillance facility for about 30 years prior to its disposal in a deep geological formation. The first such facility became operational at Tarapur in 1999 and can store waste generated during 40 years of operation of two nuclear reactors of 220 MWe capacity. Plants for managing all types of radioactive wastes have been set up and are operating along with every nuclear facility in the country.



Kalpakkam Reprocessing Plant (KARP) with cell complexity.

Fast Breeder Programme

Studies with regard to the content of the FBR programme and the type of test reactor to be built were undertaken in the early 1960s. The construction of FBTR was started in 1972 and completed in 1984. Critical components of the reactor -- like the reactor vessel, rotating plugs, control rod drive mechanisms, sodium pumps, steam generators, remote fuel handling machines, turbo-alternator and instrumentation and control packages -- were manufactured in India. Foreign input constituted only 20 per cent of the total cost, and it was mainly towards knowhow and cost of raw materials.

An important achievement was the fabrication of mixed carbide fuel at BARC. This indigenously designed and developed fuel was unique, as the mixed carbide fuel core was being used as the driver for the first time anywhere in the world. The fuel burn-up now has crossed 72,000 Mwd/t. As a logical follow-up of FBTR, it was decided to build a prototype fast breeder reactor (PFBR) and the detailed design work was taken up at the Indira Gandhi Centre for Atomic Research (IGCAR). The design work has been completed and technology development for the PFBR is in progress, in collaboration with Indian industry. The construction of PFBR is scheduled to begin in 2001-02.

Evolution of Research and Development

The profile of the R&D programmes being pursued in the research centres of the DAE has kept changing with the evolution of the country's total nuclear programme. To cite an instance from the experience of BARC, in the early years of the evolution of the programme involving setting up of PHWRs, in addition to R&D on reactor systems and components and process development for the fuel cycle and the heavy water plants, BARC provided support to nurture competence in various sectors such as the manufacture of complex equipment, plant construction, acceptance testing and calibration of equipment and components being manufactured for the first time by Indian industry or in-house facilities. Now, when the programme

is well developed, many of these activities are being conducted by industry. On the other hand, newer activities involving R&D focused on technologies related to repair and refurbishment had to be taken up at BARC, to take care of the emerging needs of operating power reactors. Plant life management has now become a major programme which requires a lot of specific data to be generated, and this is being done at BARC. Adequate experience has been acquired in this area as well. Having reached a degree of maturity in the PHWR programme, the focus has once again shifted, and BARC is now working on new reactor systems, particularly the Advanced Heavy Water Reactor (AHWR). This reactor aims to utilize vast reserves of thorium available in India and incorporates several passive safety features which are planned to exceed current international expectations. Indian technology in this area expects it to become a forerunner of similar systems, which may be developed here or in other countries. To verify some of the design features, thermosyphon studies have been conducted on specially built experimental facilities in BARC. Further, a low- to medium-pressure experimental facility is being set up at the Indian Institute of Technology, Mumbai. Engineering development of this reactor is progressing well and we hope to begin construction in a few years. Meanwhile, development efforts in the fuel cycle area have to match the needs of the emerging reactor programme. This, in fact, has been the case with all activities at BARC.

RADIATION FROM RADIO-ISOTOPES AND FROM ACCELERATORS HAS A VARIETY OF APPLICATIONS, INCLUDING HEALTH CARE, AGRICULTURE, FOOD PRESERVATION, INDUSTRY AND RESEARCH.

Safety of Nuclear Power

The DAE has accorded a prime position to safety in all its activities through the entire nuclear fuel cycle, from prospecting and mining of ores to management of waste. This encompasses all aspects of safety concerns -- nuclear, radiological, industrial, and fire, -- as well as environmental protection and occupational health. Safety is also an important subject for research and development in all the units and dedicated groups are involved in continuous monitoring and upgrading of systems based on domestic experience and that gained elsewhere.

The NPCIL has gathered operating experience amounting to over 170 reactor-years with a good record in the safety of operating personnel, the public and the environment. Safety measures (in all activities) are in comformity with the norms stipulated by an independent body, the Atomic Energy Regulatory Board (AERB). These norms are also in line with international standards.

Radiation Technology Applications

Radiation from radio-isotopes and from accelerators has a variety of applications, including health care, agriculture, food preservation, industry and research. Research reactors at Trombay regularly produce a variety of radio-isotopes and meet a major part of the demand in the country. In addition to research reactors, power reactors too have been equipped to produce cobalt-60. Work on the development of accelerators is being pursued at Centre for Advanced Technologies (CAT), Indore, and at BARC. Development of radiation technology applications is a major thrust area in the R&D programme at BARC. These applications are being commercialized by the Board of Radiation and Isotope Technology (BRIT).

Health Care

Investment in R&D health care has resulted in the setting up of a Radiation Medicine Centre (RMC) as part of BARC in Mumbai, which has become the nucleus for

The Variable Energy Cyclotron Centre

The Variable Energy Cyclotron Centre (VECC) at Kolkata has been operating the nation's largest and the first indigenously built Cyclotron in the country, providing charged particle beams of various energies. It has been serving the research needs of a distinguished community of scientists belonging to 36 national laboratories and universities.

The first ever Electron Cyclotron Resonance (ECR) Ion Source, the latest successful heavy ion source, has been designed and commissioned in the Centre. The Heavy Ion Acceleration Programme has resulted in the first heavy Ion beams beyond 6MeV/nucleon in the country. VECC has undertaken the project to construct a K500 Superconducting Cyclotron, the seventh of its kind in the world. This will open a new era of frontline experiments in the fields of medium energy heavy ion physics, materials science and biology. As a policy VECC has been using indigenous technology involving reputed Indian manufacturers in the development and construction of the accelerator.

The first Isotope Separator On Line (ISOL) system in the country was indigenously designed and fabricated in the Centre for the study of exotic nuclei. The Regional Radiation Medicine Centre (RRMC) has been set up by the VECC in collaboration with the Thakurpukur Cancer Centre and Welfare Home, to extend the benefit of nuclear diagnostic facilities to the economically weak communities in the eastern region. A laboratory has been set up for collecting helium gas from hot springs at Bakreshwar and Tantloi. Recovery of 99.9 per cent pure has been accomplished.

The Centre has contributed in a substantial way in the CERN-India Collaboration Programme by fabricating a Photon Multiplicity Detector (PMD), which has been successfully used at CERN, Geneva, for the detection of a possible signature of Quark Gluon Plasma. In the next phase of experiments with Large Hadron Collider, the Indian team led by VECC will contribute a totally indigenous PMD to the ALICE experiment. Detector of a similar design has been proposed and approved for STAR experiments at the RHIC, BNL (USA).

the growth of nuclear medicine in the country. Similarly, Tata Memorial Centre (TMC), a fully autonomous institute aided by the DAE, provides comprehensive treatment for cancer and allied diseases and is one of the best internationally. It carries out a vast number of patient investigations every year (about 800,000 pathological investigations in 1999-2000). To cater to the requirements of the eastern region of the country, a regional radiation medicine centre has been set up at Kolkata as a part of the Variable Energy Cyclotron Centre (VECC). The facilities include those for *in vitro* studies like RIA and IRMA, gamma cameras for diagnostic and 4MeV LINAC for therapy. Radio-pharmaceuticals and other preparations for these and several other medical centres in the country are regularly supplied by BRIT, which runs a comprehensive programme for this purpose based on the R&D generated at BARC.

Agriculture and Food

Application of radiation to agriculture has resulted in the release of 22 improved varieties of seeds, which are contributing directly to the increase of GDP in the country. Of these mutant varieties, blackgram (urad) accounts for 95 per cent of the cultivation of this pulse in the State of Maharashtra. At an all-India level, four BARC blackgram varieties account for over 49 per cent of the total national breeder seed indent of all the blackgram varieties taken together. Groundnut variety TAG-24 is very popular and accounts for 11 per cent of the national



ISOMED plant at Trombay.

breeder seed indent. At a conservative estimate, these varieties constitute a GDP of over Rs.10,000 millions per year.

Research done in BARC and other centres in the world, has clearly demonstrated the advantages of food preservation by irradiation, and the Government of India has cleared several items for radiation processing. Setting up of such plants is expected to reduce the percentage of food that is lost due to various causes and provide the means for improving food hygiene and facilitate export.

One spice irradiator is already operating at BRIT in Navi Mumbai, to treat items requiring high doses. A Proton irradiator at Lasalgaon, near Nasik, is being set up by BARC and will be completed in the year 2001 to treat items requiring low doses. Efforts are being made to encourage other agencies to set up such plants in the private sector.

Industry

Applications of radiation technology for industry span a wide range, including radiography, water hydrology, gamma scanning of process equipment, use of tracers to study sediment transport at ports and harbours, flow measurements, pigging of buried pipelines and water hydrology in general. All these applications are in use and have made significant contributions to Indian industry. For example, the country's expertise in gamma scanning has been used by almost all the major petrochemical companies for troubleshooting in process equipment and this has resulted in minimizing downtime and production loss costs, which could be of the order of several crores per day for such big units. BARC has handled about 20 such scannings every year for the past five years. Radiotracers have been utilized to study sediment transport at almost all the major ports and harbours. Such studies have provided guidance for desilting operations, increasing the time intervals between desilting campaigns and thus saving costs. On a conservative estimate, savings to the nation due to isotope application related services like gamma scanning, blockage and leakage detection, RTD studies and sediment transport studies amount to over Rs.20,000 millions per year.

Social Benefits

Over 6,000 technicians have been trained in the use of radiography and they have found employment in India and abroad, where the certification provided by BARC is well recognized. BARC has also developed many applications using electron beam machines, for radiation processing of products such as cross-linking of polyethylene insulation, heat shrinkables, and vulcanization of natural rubber.

BARC has developed desalination technologies based on multi-stage flash (MSF) evaporation, reverse osmosis (RO) and low temperature vacuum evaporation. A 425 cu.m/day MSF desalination plant is in operation at Trombay. Plants based on BARC's RO technology have been set up in rural areas for purification of brackish water. Currently, BARC is setting up a 6,300 cu.m/day capacity desalination plant using MSF-RO technology at Kalpakkam using nuclear heat from the Madras Atomic Power Station.

Technology Development

Research centres of the DAE have been at the forefront of development of advanced and strategic

technology and these have had a galvanizing impact on Indian industry. In recent years, areas that are receiving special attention are, lasers and accelerators.

Accelerator Programme: CAT has constructed the Synchrotron Radiation Source (SRS) Indus-1, the first such machine in the country. This consists of three accelerators, a 20 MeV microtron, a 450 MeV booster synchrotron and a 450 MeV storage ring. All three accelerators have been designed, developed, fabricated and commissioned indigenously. Current was stored for the first time in April, 1999, and the machine has been in routine operation since then. Scientists have been able to store 192 mA of current against the design value of 100 mA. Of the five beam lines planned, two have been commissioned. Work for the construction of the second SRS (namely 2.2 GeV Indus-2) is progressing to schedule. All the subsystems have been designed and prototypes built whenever necessary. After successful tests of the prototypes, fabrication has been entrusted to the industries. Indus-2 is expected to start operating by the middle of 2002.

CAT has also developed a 750 keV, 20kW DC accelerator which is in the initial phase of commissioning. It is expected to be fully operational by the end of 2001. This accelerator can be used for radiation processing of paper pulp, surface modifications, paint and resin curing and other industrial applications. A radiotherapy machine based on the microtron is also under development at CAT. In addition, CAT is developing two types of accelerators for radiation processing of agricultural products and sterilization of medical products. At BARC, the 500 keV accelerator is being tested for longer duration at higher power. The accelerator ILU-6, hitherto operating at BARC, Trombay, has been moved to the BRIT campus in Navi Mumbai to provide easy access to industrial users.

VECC has been operating at Kolkata for the past two decades and now construction of a super-conducting cyclotron has been started there.

THE DAE HAS A MAJOR PROGRAMME TO DEVELOP LASERS FOR R&D, INDUSTRIAL AND MEDICAL APPLICATIONS. THE SURGICAL CO_2 LASER SYSTEM DEVELOPED BY CAT HAS BEEN USED FOR A WIDE RANGE OF SURGICAL MODALITIES INCLUDING ENT AND GYNAECOLOGY.

Laser Programme: The DAE has a major programme to develop lasers for R&D, industrial and medical applications. The surgical CO_2 laser system developed by CAT has been used for a wide range of surgical modalities including ENT and gynaecology. About a dozen such systems have been supplied to hospitals around the country. A 4 kW CO_2 laser for industrial applications has been developed at CAT. This laser has been used for several studies on laser cutting, welding, alloying and cladding. A 10 kW CO_2 laser has also been developed at CAT and is already providing 7.5 kW of continuous power. CAT has also designed a high repetition rate pulsed TEA laser which gives peak power of more than 1 MW at 500 Hz repetition rate. This laser has been used for studies on separation of carbon isotopes. CAT has also developed several types of NdYAG lasers suitable for R&D and medical applications and developed and supplied fully automatic four-axis computerized laser welding station, to a manufacturer of cardiac pacemakers in India. A laser engraver based on 100 W Nd:YAG laser has been developed to enable engraving on any material with a high degree of precision; it can be connected to a Personal Computer

and programmed. One such unit has been supplied to a company manufacturing solar cells.

Technologies to Other Agencies

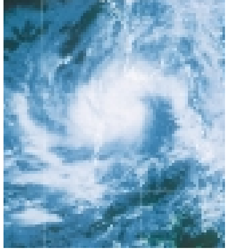
While working towards fulfilling its mandate, the DAE has developed capabilities in several hi-tech areas which are of interest to other agencies as well. Whenever a request is received for assistance in a field where it has the expertise, DAE provides the help. To quote a few examples, BARC has completed the development of a finite element based software package specially tailored for rotor dynamic analysis of turbopumps required for indigenous development of cryo-engines. Nickel-titanium shaped memory sleeves for the lightning insulator assembly have been developed in BARC. These components were certified for airworthiness and have been extensively used in the Light Combat Aircraft. BARC has provided consultancy to the Department of Ocean Development for recovery of cobalt and nickel from leach liquor obtained by processing of polymetallic nodules. The DAE is also collaborating with Vikram Sarabai Space Centre for the development, testing and qualification of a 250 kW simulation plasma source called 'constricted arc plasma generator' for testing strategic thermal protection systems for rocket motors and re-entry simulator devices. Expertise acquired by BARC in the development of reactor control systems has been also used for providing antenna controls for a number of strategic projects. Similarly, expertise acquired by BARC in non-destructive testing and digital signal processing techniques has been used for the development of a pipe inspection gauge for monitoring the health of cross-country oil pipelines for the Indian Oil Corporation.

Basic Research

The DAE places high importance on basic research. All disciplines in nuclear sciences and several science disciplines where nuclear techniques play a role, are covered by this programme, which is broad-based enough to enable use of the DAE facilities by scientists from other organizations as well as provide support to nuclear science activities there. Apart from the four R&D centres BARC, Mumbai; CAT, Indore; VECC, Kolkata; and IGCAR, Kalpakam; there are aided institutions such as Tata Institute of Fundamental Research, Saha Institute of Nuclear Physics, Institute of Physics, Harish-Chandra Research Institute, Institute of Mathematical Sciences, Cancer Research Institute and Institute of Plasma Research, which are engaged in basic research activitites spanning a broad range of disciplines.

The DAE also offers several opportunites to scientists from other institutions in India and abroad to interact and collaborate on research activities of mutual interest. The Board of Research in Nuclear Sciences enables such support to Indian scientists, while those from abroad are supported through several bilateral cooperative arrangements or through schemes sponsored by international organizations like the International Atomic Energy Agency in Vienna, the Third World Academy of Sciences in Trieste and others.

In conclusion, it may be stated that the DAE is manned by trained scientists and engineers, who are relentlessly working towards fulfilling the mandate given to them by the nation, by developing technologies having direct and widespread societal benefits. Nuclear power plants are working well; application of radiation technology to health care is benefiting a large number of patients on a regular basis; improved crop varieties are helping to increase the agricultural output; and radio-isotopes and tracer techniques are helping industry in many ways. It has been able to reach this level because of the broad R&D base that has been nurtured over the years. India is happy to share its experience with scientists from the third world countries and collaborate in areas of mutual interest.



CHAPTER XXX

SPACE PROGRAMME

The first successful satellite launch by the Soviets in 1957 ushered in the space era. At initial stages, critical military applications, national prestige and enabling space exploration were the main drives for the development of satellites and satellite launch vehicles. In later years, many civilian applications of satellites have been identified and extensively developed. Dominated by satellite communications, these civilian applications have now become the main motivating forces for the space programmes pursued by many other countries. As for the future, the new frontiers of space research promise the establishing of space colonies and inter-planetary travel, and increasing our understanding of the evolution of the universe. In the field of space applications, space-borne observations are looked upon as a very powerful and unique technique for a variety of applications ranging from weather forecasting to generation of an information base relevant to sustainable development of natural resources.

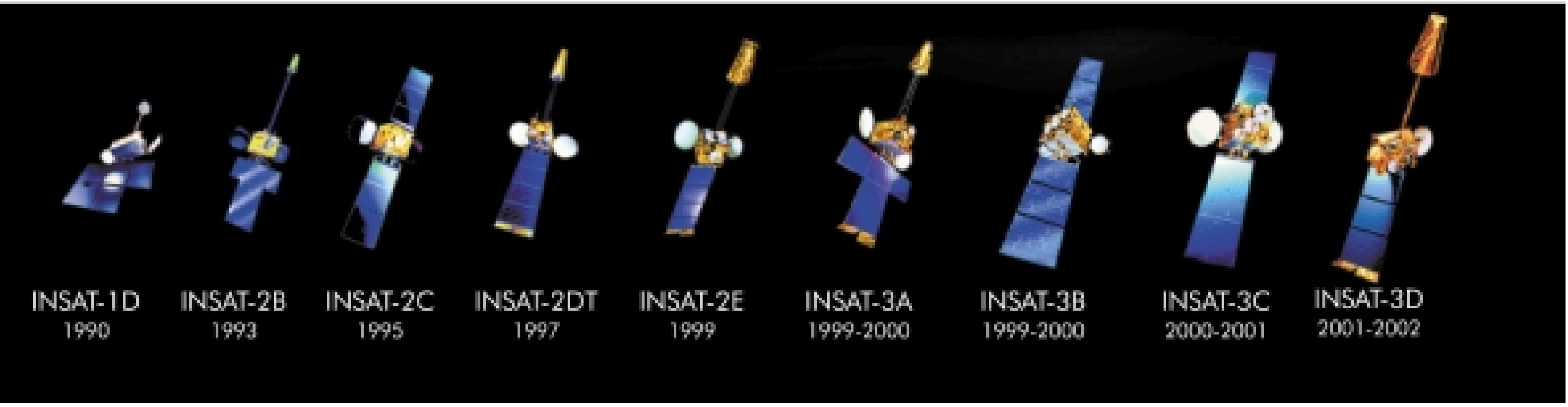
India is amongst the first few countries to realize the potential of space technology and its applications. The pioneer of the Indian space programme, Vikram Sarabhai, under whose chairmanship, the Indian National Committee for Space Research (INCOSPAR) was formed in 1962, had cherished a dream that India should be second to none in the application of advanced technologies, like space, to solve the real problems of humanity and society. In 1972, the Indian Space Programme was formally organized with the setting up of the Space Commission and the government funding it through the Department of Space.

> THE INDIAN SPACE PROGRAMME IS ONE OF THE MOST SUCCESSFUL AND COST-EFFECTIVE ENDEAVOURS GIVING WIDE RANGE OF BENEFITS TO THE NATION AND SOCIETY.

SATELLITE COMMUNICATION

The potential of space technology for mass education, especially in terms of immediacy, potency, visual power and outreach was recognized in the early 70s. Keeping in view the larger aspects of education, especially rural education, India launched the Satellite Instructional Television Experiment (SITE) in 1975-76 to telecast a series of educational TV programmes on health, family planning, agriculture, and adult education covering 2,500 Indian villages via the US satellite, ATS-6. It was the largest sociological experiment ever carried out in the world. The Satellite Telecommunication Experiment Project (STEP), conducted using Franco-German SYMPHONIE satellite during 1977-79, was another major demonstration of long-distance satellite telecommunication application of space. India also launched its own APPLE (Ariane Passenger Payload Experiment), an experimental communication satellite, in June 1981, using the opportunity offered by the European Space Agency (ESA) to put this satellite on board the third developmental flight of Ariane.

INSAT SATELLITES



A major development took place during 1980s, through the establishment of the operational Indian National Satellite (INSAT) system, for providing indigenous services in telecommunications, TV broadcasting, meteorology and disaster warning. The INSAT series, commissioned in 1983, has today become one of the largest domestic satellite systems in the world, comprising five satellites. The last satellite of the second generation INSAT-2 series, INSAT-2E, was launched from Kourou, French Guyana, on April 3, 1999.

Work on INSAT-3 series of satellites has already begun. Five satellites in the INSAT-3 series have been planned and the first satellite, INSAT-3B, has already been launched in March 2000. The INSAT system has a unique design, combining telecommunication, television/radio broadcasting and meteorological services upon a single platform. The involvement of various users like the Department of Telecommunication, Ministry of Information and Broadcasting, Indian Meteorological Department, has enabled proper tuning of INSAT system towards identified national developmental needs.

The demonstrated space applications in SITE and STEP of the 1970 were transformed to practical and operational systems through INSAT. Today, INSAT links about 450 earth stations set up in the country, including those located in inaccessible regions and off-shore islands. Besides, there are about 8,500 Very Small Aperture Terminals (VSATs), including those installed by the National Informatics Centre and private networks, catering to corporate houses.

Television in India now reaches about 85 per cent of its population through over 1,000 TV transmitters linked via INSAT. Educational programmes of over 100 hours are telecast every week. The INSAT system has become a powerful tool for training and developmental education and is used by various agencies to provide continuing education, conduct *in-situ* training for industrial employees, social welfare personnel and training of *Panchayat Raj* (village governance) workers.

India continues to emphasize the use of INSAT for rural upliftment. A pilot project that started in November 1996, in a tribal district of Madhya Pradesh in Central India is now in progress to educate the indigenous community on various aspects of health, hygiene, family planning and women's rights. This project is being expanded to cover more villages and is expected to lead to a unique space-based system that will be dedicated to the development of rural society. Similar projects are being initiated in several other states.

Weather Forecast and Disaster Management

Indian agriculture predominantly depends on the monsoons and precise forecasting of weather assumes a great significance. Large populations living on the eastern and western coasts face devastating cyclones very frequently. Thus, precise weather forecasting and warnings on impending disasters is

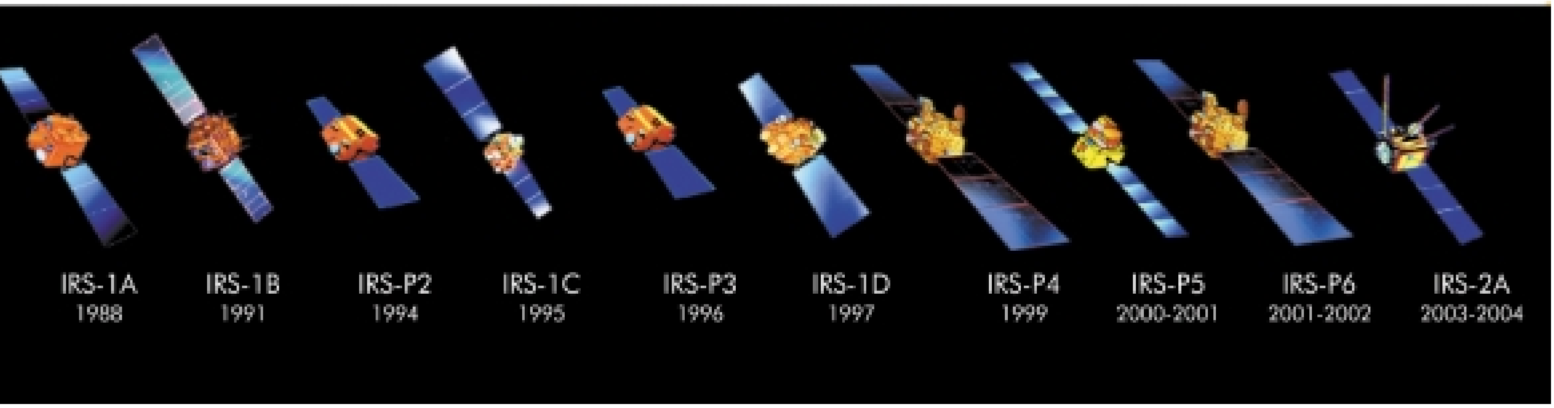
very important. This is the reason why India included meteorological instruments on its INSAT, making it a unique multipurpose satellite system. The cloud imageries collected by the satellites and over a hundred meteorological data-collection platforms installed all over the country that relay local weather parameters via the INSAT, have contributed greatly to improved meteorological services. The twin capability of communication and meteorological imaging of INSAT is effectively used not only to predict cyclone tracks but also to issue warnings to the population likely to be affected. About 250 disaster warning receivers have been installed for this purpose along the cyclone-prone east and west-coast of India. Several thousand lives have been saved by the INSAT disaster warning system through timely evacuation.

Management Of Natural Resources

India has 3.3 million km^2 land area with varied physical features ranging from the snow-covered Himalayas in the north to tropical forests in the south and from regions in the east receiving highest rainfall in the world to the arid deserts of Rajasthan in the west. India is also blessed with a vast natural wealth, yet to be exploited fully. A coastal belt of 7,500 km has a store of rich aquatic resources. What better way can be there to monitor and manage the natural resources for a large country like India than through the use of the powerful tool of space-based observation systems? India not only demonstrated the potential of space-based remote sensing in the 1970s using data received from the US satellite, LANDSAT, but also went on to build its own experimental satellites, BHASKARA-1 and BHASKARA-2, which were launched in June 1979 and November 1981, respectively. India became one of the few countries to develop its own operational Indian Remote Sensing Satellite (IRS-1A) in March 1988, and now has the largest constellation of five remote sensing satellites, IRS-1B, IRS-1C, IRS-1D, IRS-P3, and IRS-P4 in operation. Of these, IRS-1C and IRS-1D, are the best civilian remote sensing satellites in the world. IRS-P4 (OCEANSAT-1) launched in May 1999 is used for monitoring ocean resources and for understanding the atmosphere over the oceans. Two more



IRS SATELLITES

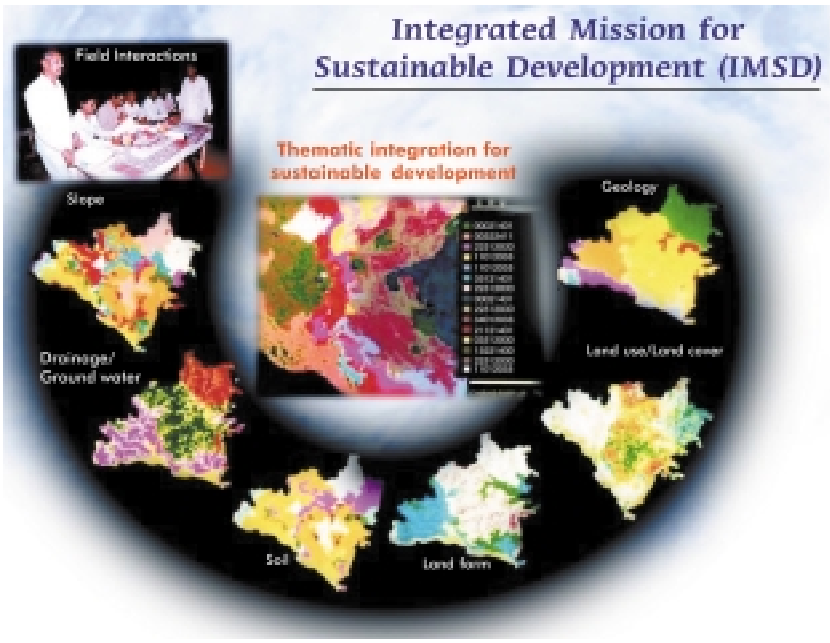


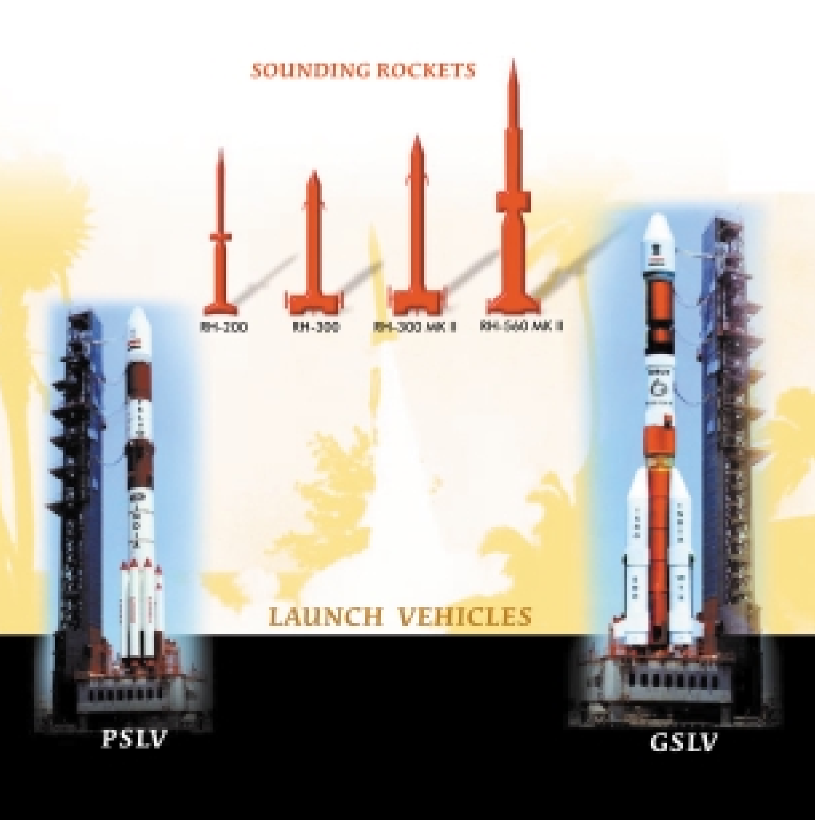
satellites, IRS-P5 for cartographic applications and IRS-P6 for resources survey, are planned for launch in the coming years.

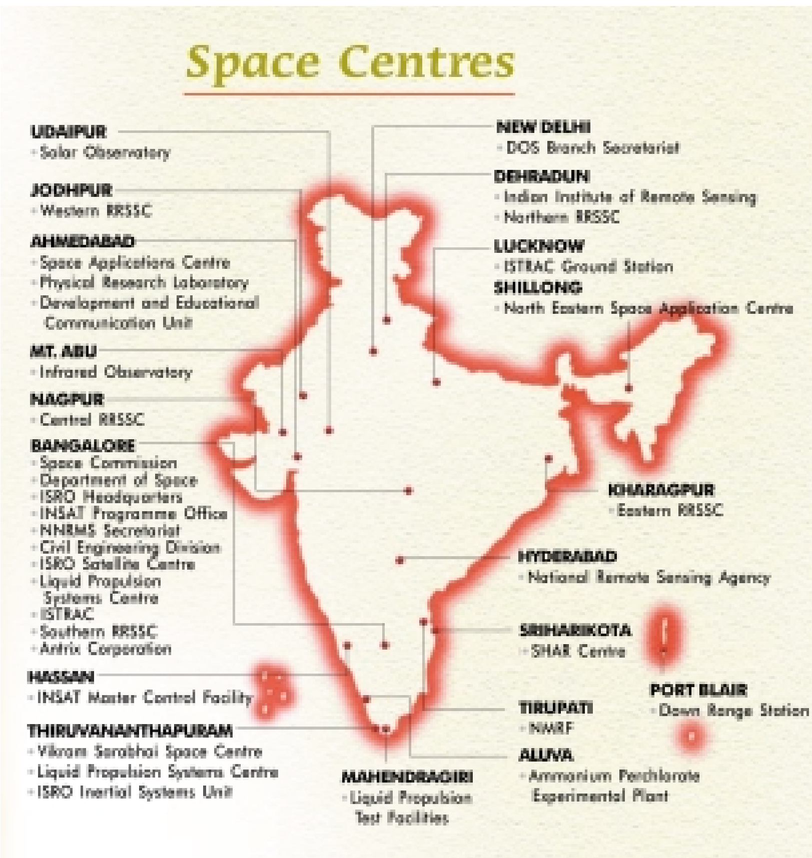
The IRS system has brought in a sea change in India's resources monitoring and management techniques. Data from IRS is used for estimation of acreage and yield of important crops, like wheat, rice, sorghum, oil seeds and sugarcane, and other applications such as forest survey, forecasting drought conditions, flood mapping and demarcation of flood-risk zones, land use and land cover mapping for agro-climatic planning, waste land mapping and their classification for possible reclamation, preparation of hydro-geomorphological maps for locating sites for borewells, monitoring and development of irrigation command areas, snow-cover and snow-melt run-off estimation of Himalayan rivers for optimal use of water. Data from IRS are also used in urban planning, alignment of roads and pipelines, detection of underground fires in collieries, marine resources survey, mineral prospecting, and so on. A unique application of data from IRS is in the Integrated Mission for Sustainable Development (IMSD) which is aimed at the generating locale-specific prescriptions for development at micro-level. The impact of IMSD is already being felt in areas where prescriptions generated have been actually implemented. The figure on the right shows various aspects of IRS satellite system, data and its applications related to sustainable development.

Indigenous Launch Vehicle Programme

India realised quite early that sustaining the space programme in the long run would depend on indigenous technological capabilities. Keeping this in view, besides building satellites, India embarked on satellite launch vehicle development in the early 1970s. The first experimental launch vehicle SLV-3 was carried out in 1980. An augmented version of this vehicle, ASLV, was launched successfully in 1992. India has now acquired a significant capability in the launch vehicle area with the successful development of Polar Satellite Launch Vehicle (PSLV), capable of putting a 1,000-1200 kg class satellite into 820 km polar sun-synchronous orbit. PSLV is







being offered to launch the satellites of other countries and has launched two small satellites, one for Korea and another for Germany along with India's IRS-P4 in May 1999. More space agencies are expected to use PSLV for placing their satellites in orbit; a European satellite PROBA is scheduled for launch as a piggy back on board next PSLV.

The Geo-synchronous Satellite Launch Vehicle (GSLV-D1) had its maiden successful flight on April 18, 2001, from Sriharikota injecting the G-SAT 1 satellite into ~180 x 32,155 km geo-synchronous transfer orbit (GTO). The adjoining figure shows different types of sounding rockets and satellite launch vehicles developed and launched by ISRO.

Space Science Research

The initial thrust for Indian space programme came from the requirement of scientists to carry out investigations in aeronomy as well as in astronomy by conducting space-based experiments. Apart from developing technologies for sounding rockets and balloon borne instrumentation, ISRO has established complementary ground-based facilities, particularly for scientists from universities and academic institutions. The major areas of investigation in space sciences have been high-energy cosmic ray variability using neutron/meson/Cerenkov monitors, equatorial electrojet and spread-F ionization irregularities, ozone, aerosol and cloud phenomena, middle atmospheric radiation, dynamics and electrodynamics, solar physics, IR astronomy, neutron star and black hole astrophysics, planetary science and origin/evolution of life and so on. Also, India has recently launched scientific payloads to study celestial gamma ray bursts and X-ray sources. For conducting atmospheric research with high resolution, the Mesosphere, Stratosphere and Troposphere (MST) radar has been established at Gadanki near Tirupati. The ISRO has enabled participation of scientists in major international science campaigns, like monsoon experiment (MONEX), middle

atmospheric programme (MAP), ISTEP, and INDOEX by providing the financial, technological and other assistance.

Based on the interest shown by a large number of space scientists in India and their suggestions, several new proposals and activities have been initiated by ISRO. Some of the major ones include (a) ASTROSAT: a multi-wavelength dedicated satellite mission for high-energy astronomy. The satellite is likely to carry soft and hard X-ray detectors and imaging payloads, all sky X-ray monitors and a UV/optical telescope system, (b) SOXS: The Solar X-ray Spectrometers payload development on board GSAT, for studying solar activity and flaring phenomena, (c) CRABEX: The Coherent Radio Beacon Experiment payload on board geo-stationary satellite and a ground-based chain of receivers located at various universities and research institutions for developing ionospheric tomography or 3-D models of ionization and their structure, (d) Planetary exploration/science: competence building in planetary science studies and also development of sensors for planetary probes/missions to the moon or to asteroids or nearby planets, and (e) Microgravity science/exploration programme: National workshops and meetings have been held to define novel scientific experiments for such a programme and proposals selected with potentials for space-borne experiments either in a balloon drop system or in a space recovery capsule.

Industry Participation

The national investment to sustain the space programme not only provides a significant and profitable domestic market for Indian industry, but also helps it to acquire technological muscle to enlarge its capability for increasing the value-added component in other areas and eventually capture a part of the growing international market in high technology applications. Hence India has encouraged active participation of industry in its space programme which in turn has led the industry to upgrade its own technological skills. Also, as a spin-off, a large number of technologies developed under the space programme have been transferred to industries for commercial applications. A number of major industries have now set up exclusive fabrication divisions to meet the demands of the national space programme. A large number of systems required on ground, such as remote sensing data processing equipment, communication earth stations and terminal equipment, have opened up a fairly large market for industry.

Human Resource Development

A constant induction of human power to carry on the task of continuous research and development is another vital element that sustains the space programme. Towards this end, Indian space programme has established a strong interface with academia, for example, the scheme of Research Sponsored by ISRO (RESPOND) under which grants for undertaking research projects on subjects relevant to the space programme are financially supported at universities, academic and research institutions by ISRO.

International Cooperation

International cooperation has been pursued from the inception of the Indian space programme. The establishment of the Equatorial Rocket Launching Station at Thumba, conduct of space application demonstrations, like SITE and STEP, and launches of experimental satellites, like Aryabhata, Bhaskara and APPLE, have involved cooperation with other countries including USA, the former Soviet Union, France, Germany and international space agencies. India has cooperative agreements with several countries and has set up two Local User Terminals (LUT) and the Mission Control Centre (MCC) as part of the COSPAS-SARSAT network, under the international satellite-aided search and rescue programme. India also shares its experience in space applications with other developing countries by training their personnel under a programme called SHARES. The UN-

INDIAN SATELLITES

NAME	DATE OF LAUNCH	WEIGHT (KG)	LAUNCH VEHICLE	LAUNCHED BY
ARYABHATA	19.04.1975	358	INTER COSMOS	USSR
BHASKARA-1	07.06.1979	444	INTER COSMOS	USSR
RS-1	18.07.1980	35	SLV-3	INDIA
RS-D1	31.05.1981	38	SLV-3	INDIA
APPLE	19.06.1981	670	ARIANE	FRANCE
BHASKARA-2	20.11.1981	436	INTER COSMOS	USSR
INSAT-1A	10.04.1982	1150	US DELTA	USA
RS-D2	17.04.1983	41.5	SLV-3	INDIA
INSAT-1B	30.08.1983	1194	SPACE SHUTTLE	USA
SROSS-1	24.03.1987	150	ASLV	INDIA
IRS-1A	17.03.1988	980	VOSTOK	USSR
SROSS-2	13.07.1988	150	ASLV	INDIA
INSAT-1C	22.07.1988	1190	ARIANE	FRANCE
INSAT-1D	12.06.1990	1293	US DELTA	USA
IRS-IB	29.08.1991	990	VOSTOK	USSR
SROSS-C	20.05.1992	106	ASLV	INDIA
INSAT-2A	10.07.1992	1906	ARIANE	FRANCE
INSAT-2B	23.07.1993	1932	ARIANE	FRANCE
IRS-1E	20.09.1993	845	PSLV	INDIA
SROSS-C2	04.05.1994	113	ASLV	INDIA
IRS-P2	15.10.1994	904	PSLV	INDIA
INSAT-2C	07.12.1995	2050	ARIANE	FRANCE
IRS-1C	28.12.1995	1250	MOLNIA	USSR
IRS-P3	21.03.1996	920	PSLV	INDIA
INSAT-2D	04.06.1997	2070	ARIANE	FRANCE
IRS-1D	29.09.1997	1200	PSLV-C1	INDIA
INSAT-2DT	(PROCURED IN ORBIT FROM ARABSAT IN JANUARY 1998)			
INSAT-2E	03.04.1999	2550	ARIANE	FRANCE
IRS-P4	26.05.1999	1050	PSLV-C2	INDIA
INSAT-3B	22.03.2000	2070	ARIANE	FRANCE
GSAT-1	18.04.2001	1530	GSLV-D1	INDIA

SLV–SATELLITE LAUNCH VEHICLE **ASLV**–AUGMENTED SATELLITE LAUNCH VEHICLE **PSLV**–POLAR SATELLITE LAUNCH VEHICLE
GSLV–GEO-SYNCHRONOUS SATELLITE LAUNCH VEHICLE **RS-1**–ROHINI SERIES **APPLE**–ARIANE PASSENGER PAYLOAD EXPERIMENT
SROSS–STRETCHED ROHINI SATELLITE SERIES **INSAT**–INDIAN NATIONAL SATELLITE **IRS**–INDIAN REMOTE SENSING SATELLITE

affiliated Centre for Space Science and Technology Education in Asia and the Pacific has begun its programme at the postgraduate level in remote sensing and geographical information system, satellite communications, meteorology and space science for the benefit of persons from Asia and the Pacific region. India hosted the second UN-ESCAP Ministerial Conference on space applications in November 1999.

Commercial Accruals

Even though India's space programme is primarily directed towards establishment of space systems for national development, the capability that is built in the process has started yielding economic benefits. The setting up of an exclusive commercial front, the ANTRIX Corporation, under Department of Space, in 1992, for marketing hardware and services has acted as a catalyst in this endeavour. Important commercial agreements include worldwide marketing of remote sensing data from Indian satellites, lease of satellite capacity, launch of small satellites on board PSLV, supply of satellite hardware, providing tracking support for satellites using Indian ground stations and training of personnel.

Space Expenditure

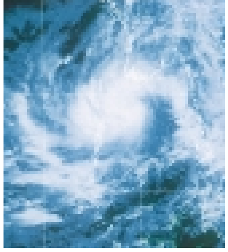
India has now established a well-integrated space programme with end-to-end capabilities for the development and application of space technology for national benefit. The execution of the programme has been well orchestrated -- starting with demonstration of end-use through large-scale experiments, developing linkages with users, passing through experimental and developmental phases of system development and finally, establishing state-of-the-art operational systems.

With a modest overall expenditure of about US



$ 2,400 million so far, India has built 29 satellites, developed three types of launch vehicles, conducted thirteen flights so far, established an elaborate infrastructure to design, build and test communication and remote sensing satellites, their launch, and their in-orbit management as well as their data processing and application, and has developed a strong human power base for undertaking frontline R&D in space. The Indian space programme has been one of the most successful and cost-effective endeavours, especially, when one looks at the wide range of benefits that have accrued to the nation and society.

As India enters the new millennium, it is necessary to sustain this programme by continuously tuning it to the fast changing requirements and updating the technology that goes into the making of these sophisticated systems. The challenges continue to grow but that is what attracts and sustains the interest of personnel working in the space programme.



CHAPTER XXXI

DEFENCE RESEARCH AND DEVELOPMENT ORGANIZATION

The government of Independent India set up the Defence Science Organization in 1948 to advise and assist the Defence Services on scientific problems and to undertake research in areas related to defence. The Defence Research & Development Organization (DRDO) was set up in 1958, by merging the units of Defence Science Organization with the then existing Technical Development Establishments of the three Services. Subsequently, a separate Department of Defence R&D was formed in 1980, to improve administrative efficiency.

The mission of the Department is to attain technological self-reliance in defence systems and weapons. To accomplish this, the Department has the mandate to design, develop and lead on to production of the state-of-the-art weapon systems, platforms, sensors and allied equipment to meet the requirements of the Armed Forces and to provide support in areas of military sciences to improve combat effectiveness of the troops.

The Department of Defence R&D executes various R&D programmes and projects through a network of 49 laboratories/establishments of the DRDO located all over India and a Centre for Military Airworthiness and Certification (CEMILAC). It also administers the Aeronautical Development Agency (ADA), a society funded by the Department, which is engaged in design and development of the Light Combat Aircraft (LCA). These laboratories and establishments execute programmes and projects in diverse fields of aeronautics, armaments, missiles, combat vehicles, electronics and instrumentation, advanced computing and networking, engineering systems, agriculture and life sciences, advanced materials and composites and Naval R&D. They also conduct specialized training programmes in these areas. The programmes are carried out by a workforce of about 30,000 including more than 6,000 scientists and engineers, supported by a budget of the order of Rs. 30,000 million.

To fulfill its objectives DRDO has a strong partnership with about 40 academic institutions, 15 national S&T agencies, 50 PSUs and 250 private sector enterprises. This has enabled the organization to minimize the effects of sanctions and technology denials, imposed by technologically advanced countries from time to time.

During its first decade, between 1948 and 1957, DRDO was mainly engaged in activities related to clothing, ballistics, operations research, and general stores. During the next decade 1958-68, many products, including small and medium weapon systems, explosives, communication systems and cipher machines were developed. The important achievements of the next decade (1969-79), during which DRDO addressed major hardware systems included, field guns, sonar systems, radar and communication equipment and aeronautical systems. Between the years 1980-90, it embarked on programmes of a multi-disciplinary nature for the development of complex and sophisticated weapon





Top: Light Combat Aircraft (LCA) in flight.
Left: Kaveri engine for LCA.

systems having latest technology. The contribution of DRDO towards self-reliance in defence systems became evident with the development of flight simulators for *Ajeet* and *Kiran* aircraft, air launched missile target *Fluffy* and various other types of ammunition, low-level surveillance radar *Indra*, electronic warfare (EW) systems and sonars. During the decade of 1990-2000, certain major programmes undertaken during the previous decade culminated in weapons and systems, like the Ballistic Tank (MBT) *Arjun*, missiles *Prithvi* and *Agni*, pilotless target aircraft *Lakshya*; combat improved T-72 tank *Ajeya*, bridge layer tank on T-72; *Sarvatra* bridging system, artillery combat command and control system, 5.56 mm INSAS rifle; light machine gun and ammunition; the super computer PACE+, sonar systems and Naval mines.

Starting out as an agency which carried out science-based technical improvements to existing systems, DRDO has grown today to a high-technology agency capable of undertaking *ab-initio* design, development and integration, leading to production of world class weapon systems meeting Qualitative Requirements of the Services. DRDO has achieved technological self-reliance in ammunition, armoured systems, surface-to-surface missiles, sonar systems, Electronic Warfare (EW) systems and advanced computing.

Achievements and Programmes

Aeronautical Systems: DRDO has already delivered pilotless target aircraft *Lakshya*, aircraft arrester barrier, a variety of brake parachutes and balloon barrage system to the Armed Forces. The Light Combat Aircraft (LCA) programme, under execution at Aeronautical Development Agency (ADA), has led to the development of several state-of-the-art aeronautical technologies and the creation of a necessary infrastructure, despite the constraint of

sanctions imposed by the advanced countries and the country's industrial base unprepared for the requisite components and advanced materials. The first LCA Technology Demonstrator (TDI) has undergone a number of successful test flights. The remotely piloted vehicle *Nishant*, is at an advanced stage of evaluation. Certain crucial elements, of the modernized avionics of Su-30 MKI aircraft being acquired by the IAF, have been supplied and successfully integrated.

Armaments: DRDO has achieved a high degree of developmental self-reliance in the area of armament and ammunition. More than 300 ammunition items based upon DRDO technology worth Rs. 50,000 million have been manufactured by ordnance factories. These include 5.56 mm calibre rifle and machine gun, anti-tank ammunition, illuminating ammunition, mines and a variety of bombs for the Air Force. The project for the development of a multi-barrel rocket system is at an advanced stage of evaluation.

Missile Systems: DRDO has established core competence in the area of surface-to-surface missiles, which has been demonstrated through development of *Prithvi* missile and its variants, demonstration of re-entry and related technologies for *Agni-I* and development of the longer range version, *Agni-II*. The surface-to-air missiles *Trishul* and *Akash* and anti-tank missile *Nag* are at an advanced stage of flight evaluation. For the first time in the world, the indigenously developed capability to hit a target at 4.18 km in top attack and the fire-and-forget mode has been demonstrated through a flight test of *Nag* missile.

Radar and Communication Systems: In spite of the non-availability of indigenous microelectronic devices and components, DRDO laboratories have successfully developed and delivered a variety of systems falling under this group including INDRA PC radar, equipment for Army Radio Engineered Network (AREN), very low frequency receivers, satellite communication terminals and secure



Agni missile.

telephones. A number of projects, for development of other radar and communication systems, are being carried forward.

Electronic Warfare (EW) Systems: DRDO developed a number of EW systems with considerable success. These include *Ajanta, Coin, Vikram* and Radar Warning Receiver (RWR) for MiG-23 and MiG-27 aircraft, which have been delivered to the Services. In addition, the self protection jammer for MiG-27, is ready for delivery. Development of an advanced RWR for MiG-21 aircraft has been completed. The current EW projects, *Samyukta* and *Sangraha* for the Army and the Navy are at an advanced stage and should reach the Services in the next few years. India is now capable of developing any type of state-of-the-art EW system for the Services.

Combat Engineering Systems: DRDO's efforts have led to successful development of a variety of complex multi-disciplinary systems including bridge layer tanks, mat fording vehicles, mine field marking equipment, mortar carrier vehicles, armoured engineering recce vehicle, armoured amphibious dozer, operation theatre complex on wheels, ward container and mobile water purification systems. The R&D expertise in DRDO and the production infrastructure in the country can now be brought together for world class engineering systems for Defence Services.

Main Battle Tank: *Arjun*, and its derivative systems have met stringent requirements of the Army successfully. This tank is contemporary to world class tanks like M1A2 of the USA and Leopard 2 of Germany. The bulk production of MBT *Arjun* is now at an advanced stage. Based on the experience gained during the development of MBT *Arjun*, DRDO has successfully integrated a 155 mm SP turret on *Arjun* derivative chassis for development of a 155 mm self-propelled weapon system. It has also modernized the T-72 M1 tank to improve its fire power, mobility and protection.

Underwater Warfare Systems: This has been another area in which a solid foundation for self-reliance has been established by successful development and delivery of a number of sonar systems, including *Simhika, Humsa, Humvad* and *Panchendriya* and a number of Naval systems including triple tube torpedo launcher and Processor Based Ground Mine and Processor Based Moored Mine. The systems in advanced stages of development include *Mihir* and *Nagan* sonars, advanced experimental torpedo *Shyena* and also wire guided torpedo.

Other Major Achievements

Advanced Computing and Software Products: DRDO has successfully developed Supercomputer PACE+, consequent to the denial of such a computer by the advanced countries. DRDO's expertise in software has been demonstrated through the development and commissioning of war games *Shatranj* and *Sangram* for the Army; *Sagar* for the Navy and air war game software for the Air Force. A landmark toward self-reliance in microprocessor technology has been achieved through development of ANUCO, a floating-point coprocessor and a 32-bit RISC processor ANUPAMA. Its processing speed is being further enhanced from 33 MHz to 350 MHz. In addition, a three-dimensional medical imaging system 'ANAMICA' has been developed. Softwares called GITA (Graphical Interactive Three Dimensional



Main battle tank Arjun.

Applications, a general purpose CAD software and AUTOLAY, a design for software manufacture is being marketed internationally. DRDO has also set up a Very Large Scale Integrated Circuits (VLSI) design facility, which has been used for developing a number of Application Specific Integrated Circuits (ASICs) like the digital signal processing chip.

Critical Electronic Components: Initiatives to achieve self-reliance in the field of electronic components has been taken by setting up facilities for production of Gallium Arsenide and Silicon devices. Under the programme, CODE, several types of components have been indigenized, like integration components, microwave components, millimeter wave components and other special types

of components required for various ongoing DRDO programmes. A facility has been created to lead to fabrication of Gallium Arsenide wafers and Monolithic Microwave Integrated Circuits (MMICs) in 1-18 GHz range. Under a co-operative venture with other S&T Departments and Industry, DRDO has contributed in setting up a silicon foundry which has the potential of making the country independent of foreign sources in respect of most of the VLSI requirements.

Electronic and Strategic Materials: DRDO has developed several types of strategic materials like 'Jackal M-1' steel for bullet-proof jackets and bullet-proof vehicles; aluminium alloy for structural applications in the Light Combat Aircraft; single crystal super alloy and directionally solidified super alloy for use in high performance aero-engines; fibre reinforced plastic (FRP) composites for immunity against small arms ammunition and missile fragments on board ships; kevlar/aramid composite material for light weight combat helmet and rare earth based high energy magnets for application in India's space programme. DRDO has undertaken certain initiatives for making the country self-sufficient in a number of strategic materials, like setting up a facility for carbon fibre and prepegs for application in aerospace structures; launching of a national programme for development of smart materials and technology development for high purity alumina substrate and PTFE soft substrate for use in microwave integrated circuits. Technology for Fullerenes and carbon nano tubes which have potential applications in stealth, smart materials and micro-electronics have been indigenized and facilities for nano tubes at 5 gm/day level has been established.

Metal/Material Processing Technologies: The technology to convert titanium tetrachloride into titanium sponge, which is a closely guarded secret of the few titanium sponge producers in the world, has been developed which will enable India to utilize the world's largest reserves of titanium which the country has. This can be gainfully utilized in defence, aerospace, oil and power sector industries. In addition, innovative processes comprising air induction melting and electro-slag refining have been developed to produce iron aluminide based advanced inter-metallics. Aluminium based particulate metal matrix structural composites for aerospace applications have also also been developed. Technologies and processes such as ion plasma deposition of protective layers and laser processing have been established. Two grades of ultra clean structural and armour steels of High Strength Low Alloy (HSLA) steel variety, copper-boron (CuBux) and armour (ARx), have been designed and developed for structural and armour applications in marine vessels.

Radar and Communication Technologies: To meet the requirements of modern radars, namely longer detection ranges, faster data rates (short reaction times) and ability to accommodate increased target densities, DRDO has indigenously developed the technology area of array design and developed expertise in the development of radiating elements, taking into account the mutual coupling, collimation and beam steering, feeds etc. A planar, phased array system has been successfully implemented in *Rajendra* radar. Another achievement is the speech secrecy systems based on state-of-art encryption techniques for telephone secrecy (speech), secrecy over radio and multi-channel (bulk) secrecy over voice and data. The satellite communication terminals, based on state-of-art techniques like spread spectrum multiple access, high grade secrecy and low bit-rate voice digitization, have been developed. One such terminal in S-band was used during the Orissa cyclone in 2000, for communication with remote villages.

Missile Technologies: During the execution of IGMDP programme, DRDO developed several technologies that have gone into various missile systems. These include: strapdown inertial guidance system, high strength low weight magnesium alloy

wings; manoeuvrable trajectory; accurately deliverable high lethality field interchangeable warheads; multiple target tracking; composite airframe; nitramine based smokeless propellant; ram rocket technology; three beam command guidance system; carbon-carbon technology; and manoeuvrable re-entry guidance and control for long range missions.

Naval Technologies: During the course of the development of indigenous surface, ship and submarine sonars and other sonar systems by DRDO, a number of technologies have been developed. These include multi-channel sonar signal conditioning and data acquisition; sonar signal processing hardware; sonar display systems; sonar simulation and sonar power amplifiers. In the development of underwater acoustic transducers of various types, special acoustic materials like polymers, polymer matrix composites, elastomers and adhesives have been developed along with expertise in engineering aspects like packaging underwater sealings and encapsulations. DRDO is a world leader in development of Impressed Current Cathodic Protection (ICCP) technology to supplement the protection provided by paints to underwater structures against sea water corrosion. Work is in progress on 'Dual Zone' ICCP system. Fire retardant intumescent paint; non skid and high performance exterior paints and polymer based materials like vibration damping material; ion exchange-cum-indicator resin and polyurethane sealant have been developed. Work is also in progress on fuel cells as an alternative source of power. In the area of underwater weapon propulsion, magnesium-silver battery technology and contra rotating motor with indigenous design and technology have also been developed. Machinery Control Room (MCR) simulators for training engine room crew have been developed. The DRDO-developed hydrophone system was used to detect Gujarat earthquake victims buried under the debris, based on which it was possible to rescue five persons.

THE DRDO-DEVELOPED HYDROPHONE SYSTEM WAS USED TO DETECT GUJARAT EARTHQUAKE VICTIMS BURIED UNDER THE DEBRIS, BASED ON WHICH IT WAS POSSIBLE TO RESCUE FIVE PERSONS.

Agriculture and Life Science Technologies: Cold desert agro-animal technologies have helped to sustain the population of Leh (Ladakh) and to meet the requirements of military and para-military forces deployed in these regions. These technologies have helped to grow off-season vegetables for soldiers and the local people. Growing of fresh vegetables locally and greenhouse cultivation during frigid winters are saving considerable transportation costs for the Army. DRDO has helped in establishing a self-sustaining village, Nang, at a height of about 4,000 m. It has developed technology for soil-less agriculture or 'hydroponics' which is very effective in areas not having suitable soil and where economy in water use is mandatory. An internationally acclaimed concept of 'radio iodine split dose therapy' for management of hyperthyroidism has been developed. In addition, several man-machine and man-medicine interface technologies and food preservation and food processing technologies have been developed.

National Infrastructure Assets

DRDO has been instrumental in creation of sophisticated and high cost R&D facilities for test, evaluation and other purposes. These may be termed assets, as these fulfill the requirements not only of DRDO but also of other scientific organizations and of the industry. A brief account of such facilities created, is presented.

Range Test Facilities: To meet the requirements of various missiles and other weapon system development programmes, a total of four launch complexes have been established: three at Interim Test Range, Balasore, and one on an island. These launch complexes suit specific requirements without affecting the natural environment in the test range. The range of instrumentation includes sophisticated radars, electro-optic tracking system, telemetry system, range computer and wide band data acquisition and processing system. With the help of these sophisticated instrumentation, the post-flight data are available within thirty minutes of the flight. In the recent past, the range facility was utilized by Ministry of Defence, Singapore, on a paid basis.

Flight Simulation Facilities: DRDO has created several flight simulation facilities to support design investigations of fighter aircraft performance, handling qualities and capabilities in close combat and mission system performance. Some of the facilities include: research flight simulation facility, pilot-in-loop flight simulation facility, air combat simulator, mission avionics systems simulator, cockpit environment facility and aircraft system maintenance simulator. A virtual reality centre has been set up to address the requirements of virtual prototyping of LCA. The Aeronautical Material Testing Laboratory (AMTL), a national facility, is one of its kind for testing aeronautical material and components. In addition, under Aeronautics Research & Development Board (AR&DB), DRDO helped in setting up of sophisticated test facilities at IISc, Bangalore, IITs, some universities and at other technological institutions like NAL, to support R&D in aeronautics and applied science. Some of these major facilities are: modified trisonic wind tunnel (NAL), 200 mm hypersonic wind tunnel (IISc), high temperature low cycle fatigue test facility (IIT-B) and full-scale fatigue test facility (NAL).

National Centre for Automative Testing: DRDO has set up a National Centre for Automative Testing (NCAT), at Ahmednagar, for testing and evaluation of automotive vehicles, their systems and components for certification for compliance of various national/international standards. Spread over an area of 450 acres, this facility consists of track testing and testing for emission, photometry, EMI and safety and has necessary supporting infrastructure to provide a one-stop solution to the requirements of Indian automative industry. A variety of test tracks and facilities are spread over an area of 450 acres. The test tracks simulate a variety of ground/road surface conditions which a vehicle normally encounters during its span of use.

Electronic Warfare Test and Evaluation Facilities: DRDO has created Electronic Systems Evaluation Centre (ELSEC) for ground integration of EW systems and testing of systems under real life conditions. A Range on Wheels (ROW), comprising six mobile ground stations has been made operational. It is a unique facility for evaluation of airborne EW systems during development, user acceptance and system enhancement phases. The setting up of EW Simulation Testing and Evaluation Station (SITES) and Microwave Components Qualification and Testing Centre (MQTC) is in progress.

Underwater Research Facilities: A premier research facility called High Speed Towing Tank (HSTT) for carrying out studies on experimental hydrodynamics related to model testing of ships, propellers and submerged bodies has been set up. An Underwater Acoustic Research Facility (AURF), a lake facility established by DRDO at Kulamavu in Idukki district of Kerala, carries out calibration and full-scale testing of underwater acoustic transducers, array and other sub-sea equipment like fish finding sonars, echo sounders and underwater communication systems. A dedicated research ship *Sagardhwani* equipped with state-of-the-art laboratories has been developed and is being used for collection of oceanographic data. Materials and

Transducers Simulated Test facility (MATS), the only one of its kind in the Asia Pacific region and one of the very few in the world, has been established recently which provides static and dynamic measurements on materials and transducers under different conditions of temperature and pressure, simulating ocean depths. The setting up of an underwater range and a cavitation tunnel facility is in progress.

R&D for Societal Benefits

Floor Reaction Orthosis (FRO): As a medical spin-off of advanced composite technology used in making missile nose cones, Floor Reaction Orthosis, a walking aid for polio patients with quadriceps muscle weakness, has been developed. This weighs only 300 gm, as against 3 to 3.2 kg for the commonly used variety, is inexpensive and can be worn easily with and without shoes. More than 2,500 such walking aids have been fitted to polio handicapped persons in camps organized for this purpose.

Coronary Stents: Using special grade austenitic stainless steel, developed for LCA and missile programmes, two types of stents have been developed for dilating constricted arteries. Over 115 stents have been fitted in patients so far. The cost of the indigenous stent is Rs. 15,000 as against Rs. 40,000 or more for the imported one.

Cardiac Pacemaker: An external pacemaker has been designed and developed for intensive care of patients suffering from degenerative heart diseases. The system has been clinically validated at Nizam Institute of Medical Sciences, Hyderabad. Efforts are being made to convert it into a portable system.

Cardiovascular Catheters: These have been developed to offer a heart patient the option of non-surgical treatment of defect within the heart and the rest of the circulatory system. The cost of the indigenous catheter would be Rs. 1,500 against Rs. 4,500 for the imported one.

Cardiac Stress Test System: A PC-based, low cost indigenous system has been developed to acquire and analyse the ECG of a person doing exercise. The system comprises a standard protocol of graded exercise programme, acquisition, analysis and documentation of ECG and trends in BP, heart rate and ECG, indicating heart abnormalities. The system hardware consists of a 12-channel ECG data acquisition system and is priced at Rs. 350,000 to 400,000 as against Rs. 1.2 to 1.5 million for the imported one. The system is in operation at Air Force Hospital, Delhi, and its technology has been transferred to trade.

Cytoscan: Using the latest pattern recognition and image processing technologies, a computer aided cancer detection device has been developed by DRDO. The system is used for diagnosis and prognosis of several cancers, including cervical and breast cancer. The system has been used for detection of cervical cancer amongst tribal women in Andhra Pradesh under Project *Tulsi*, funded by the Ministry of Social Welfare. The programme will be extended to rural areas of Bihar, Madhya Pradesh, Rajasthan and Uttar Pradesh. More than 20,000 rural women have been scanned so far.

Slit Lamp Microscope and Drishti: India's first Nd-YAG ophthalmic laser system *Drishti-1064* has been developed by DRDO. The system is used for ophthalmic applications in the treatment of glaucoma.

Dental Implants: Using commercially pure titanium, a technology has been developed to design and fabricate titanium endosteel implants and bone plates. It has tremendous application in oral and skeletal rehabilitation. The Drug Controller of India, Ministry of Health & Family Welfare, has accorded approval for multi-centric clinical trials.

Piezodent--Ultrasonic Dental Scalar: Using piezo-electric transducer technology, a device has been developed for use by a dentist to remove tartar on

the teeth. This technology is more efficient as compared with the earlier magnetic strictive technology. The device is built around highly efficient piezo-ceramic transducer and is light and compact with ergonomically designed hand piece and is equipped with a unique swivel facility for multi-directional accessibility and parking of handpiece. The technology has been transferred to industry.

Water Desalination Technology: DRDO has developed water desalination, testing and purification technologies, based on which 30 desalination plants have been commissioned in 25 villages of Barmer district of Rajasthan under Phase-I of project *Sujalam*. A water testing field kit has been developed in accordance with the requirements of National Drinking Water Mission, for quick assessment of chemical and bacteriological quality of water for potability. The technology has been transferred to industry.

Tissue Bank Facility: A tissue bank facility has been created by DRDO for preparation of radiation processed chorio-amnion grafts. The grafts are extremely useful for treatment of burn injuries. The facility can provide 2,000 grafts per year.

Avalanche Forecasting: The organization has set up a number of observatories and automatic weather stations at various locations, based on which, avalanche forecast warnings with high accuracy are being issued to areas of Jammu and Kashmir, Himachal Pradesh and Uttar Pradesh. An 'avalanche victim detector' has also been developed to locate avalanche victims and facilitate rescue operations.

HAPO Bag: DRDO has developed a High Altitude Pulmonary Oedema (HAPO) bag for HAPO patients by simulating a safe ambient pressure around the patient. A two-bedded hyperbaric chamber has been commissioned for civil application at Indraprastha Apolo Hospital, New Delhi, for carrying out hyperbaric oxygen therapy.

Jammer for RCIED: The Remote Control Improvised Explosive Devices (RCIEDs) are being used by criminal and anti-national elements by integrating devices, such as, cordless telephones, remote bell, remote control toys, garbage door openers and DTMF transceivers with explosive devices. DRDO has successfully developed a system as a counter-measure against RCIEDs. This system prevents the command signals entering the RCIED, which is initiated by a hand-held transmitter. The system can be installed on an Ambassador car for VVIP security, on Armada Jeep or a Tata Sumo vehicle, for paramilitary convoy protection.

DRDO HAS DEVELOPED A KIT FOR DETECTION AND IDENTIFICATION OF EXPLOSIVES BASED ON ANY COMBINATION OF NITROESTERS, NITRAMINES, TRINITROTOLUENE (TNT), DYNAMITE OR BLACK POWDER.

Bio-digesters: A consortium of bacteria and digesters for disposal of human waste through microbial degradation in an eco-friendly manner, for use in high altitude, low temperature areas has been developed. Some of these, installed at high altitudes and glacier regions, are functioning satisfactorily.

Explosive Detection Kit: DRDO has developed a kit for detection and identification of explosives. It can detect and identify explosives based on any combination of nitroesters, nitramines, trinitro-toluene (TNT), dynamite or black powder. The testing requires only 3 to 5 mg of suspected sample and only 3 or 4 drops of reagents.

Long-Term Storage of Tender Coconut Water: A

technology has been developed to preserve tender coconut water, a delicious natural and healthy drink rich in minerals, especially potassium. The drink is stored in aluminium cans and flexible polymeric pouches to preserve its natural characteristics up to six months. The technology has been transferred and the product is now being marketed.

Interaction with Academia

DRDO has constituted four research boards to nurture and harness talent in academic institutions, universities, R&D centres and industry. The organization provides necessary facilities for promoting basic research and to catalyse cross-fertilization of ideas with R&D agencies in other sectors for expanding and enriching the knowledge base in their respective areas. The boards provide grants-in-aid for collaborative defence-related futuristic front-line research having application in the new world-class systems to be developed by DRDO.

The catalytic role played by research boards has helped rapid growth in building capabilities in the area of aeronautical state-of-the-art systems like light helicopter, and in setting up a centre of excellence in Computational Fluid Dynamics (CFD) at the IISc, Bangalore, which is anticipated to give a boost to the designing of aeronautical systems within the country. Another centre of excellence in aerospace system design and engineering is being set up at IIT, Mumbai. A Centre for Composite Structure Technology is proposed to be set up at the National Aerospace Laboratory, Bangalore. Grants-in-aid by DRDO have led to setting up of a hyper-media digital library in IIT, Kharagpur, to the development of audio-visual training aids for aircrew, to indoctrination in air sickness and positive pressure breathing at the Institute of Aviation Medicine, Bangalore, and to the development of rarefied gas dynamic facility at IIT, Chennai.

The Armament Research Board (ARMREB) has approved projects in the fields of high energy materials, sensors, ballistics and other armament related fields. Under the Naval Research Board (NRB), projects are being pursued in five technology areas. Under Life Sciences Research Board (LSRB) projects have been supported in the areas of biological and bio-medical sciences, psychology, physiology, bio-engineering, specialized high altitude agriculture, food science and technology.

Collaboration with Industry

Eight DRDO laboratories working in the areas of advanced materials, robotics and artificial intelligence, communication systems, life-support systems, corrosion protection, advanced composites and desert technologies have been opened to the industry. Several technologies have been transferred to private industry such as the Scara robot, used for assembly jobs and the articulated robot used for material handling, welding, spray-painting etc. In the field of material science, the technologies transferred include: boropak, a chemical mixture to impart surface hardness and reduce wear and tear of ferrous and some non-ferrous metals; non-spark tools for copper titanium alloy; gigly saw for use by orthopaedic surgeons; rust converter for protection of ferrous metals against corrosion; moisture-resistant corrugated fibre board box as an alternative to timber for packing; and glacier tents for protection in sub-zero temperatures.

In a number of areas involving emerging technologies in which industries are not willing to invest setting up defence-specific manufacturing facilities, DRDO has also been collaborating with other departments as well as industry to help transform defence technologies for developing products for the civil sector. As these exercises involve long gestation periods, technological risk, lack of continuity of orders and lack of economy of scale, DRDO has assisted in setting-up dedicated facilities in such areas. Some of these initiatives are listed as follows.

Heavy Alloy Penetrator Project (HAPP): A fully automated factory for manufacturing highprecision components and assembly of Fin Stabilized Armour Piercing Discarding Sabot (FSAPDS) ammunition has

been established by DRDO at Trichy and handed over to Ordnance Factory Board. World class FSAPDS ammunition of different calibres are under regular production and have been supplied to the Army.

Bharat Dynamic Limited (BDL): A modern factory has been established for production of *Prithvi* and other missile systems being developed under Integrated Guided Missile Development Programme (IGMDP). Free flow production of *Prithvi* has been established.

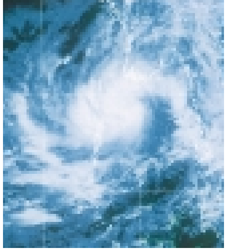
Hindustan Aeronautics Limited (HAL): An Aerospace Division has been established to provide special thrust of *Prithvi* and other missile systems being developed under IGMDP.

Non-Ferrous Technology Development Centre (NFTDC): This society has been established as an advanced technology centre with participation of the Department of Mines, DST, DRDO and Industry (BALCO, NALCO, HCL and HZL). Some of the contributions of this centre include millform of copper alloys, silver-based brazing alloys, titanium implants and master alloys for grain refinement of aluminium.

Advanced Research Centre International (ARCI): This is a cooperative venture between India, Bylo-Russia, USA and Ukraine. India is represented by DRDO and DST. This Centre has been set up for advanced research in powder metallurgy and other special processes leading to uses by both defence and civil sectors. The contributions made by this Centre include development of coating for Adour engine turbine blade and exfoliated graphite for high temperature gasket.

Training Schemes

DRDO has introduced a number of schemes for training of defence-science personnel in universities and other leading academic institutions. It also has two training institutions namely, Institute of Armament Technology (IAT) at Pune and Institute of Technology Management (ITM) at Mussoorie. These institutes provide specialized training programmes in diverse fields. The ITM has recently started conducting MBA in Technology Management in collaboration with Bhartidasan University. The IAT has been accorded the status of a deemed-to-be university. In addition, a number of laboratories conduct training programmes in disciplines of their core competence like fire-fighting and fire-engineering, wargaming softwares, special clothing and so on. To cite an example, Defence Food Research Laboratory at Mysore conducts training programmes in food science and technology, modern methods of handling, hygiene, transportation, storage and packaging of food materials; comprehensive course in food microbiology and a ten-month postgraduate programme in food analysis exclusively for Service officers. In recent years, the PG Diploma Course (recognized by the University of Mysore) has trained many civilian candidates who have been absorbed by food industries. Other short-term orientation and specialized courses are conducted at the specific request of industries and laboratories, colleges and universities. A DRDO laboratory, the Defence Research & Development Establishment at Gwalior, has been recognized as a centre for training inspectors who are to be appointed by the UN Organization for Prohibition of Chemical Weapons.



CHAPTER XXXII

DEPARTMENT OF BIOTECHNOLOGY

In 1982, following detailed deliberations with the scientific community, and based on the recommendations of the then Scientific Advisory Committee to the Cabinet, a National Biotechnology Board (NBB) was constituted by the Government to foster programmes and strengthening indigenous capabilities in this newly emerging discipline. Subsequently, a separate Department of Biotechnology (DBT) was set up in February, 1986. Since then a strong infrastructure for biotechnology research and services has been created in both national laboratories and academic institutions. An integrated programme for generating human resource and encouraging research and development was initiated. Support was provided for basic, applied and product-oriented research, with a view to attaining excellence and product development.

Biotechnology scenario in the world is changing rapidly. The announcement of working draft of Human Genome, International Rice Genome Initiative, development of Transgenic Rice with Pro-vitamin A and complete genome sequencing of a number of small organisms are some illustrative examples. These innovations have long term benefits for development of products and processes for health care, agriculture and allied areas for bioindustrial development.

During the last decade the DBT has adopted a holistic approach to the accelerated pace of progress of New Biology and Biotechnology based on the biological wealth of the country. The main thrust of the programmes was on research support on long-and short-term basis leading towards scientific excellence, development of new products or processes, large-scale demonstrations, validation of R&D leads, involvement of user agencies and industries, technology development and transfer, innovations for patenting purpose. Emphasis was also laid on establishing new centres of excellence, infrastructural facilities, programme support in priority areas, expansion of bioinformatics network and human resource development. The effort has been to ensure that biotechnology tools are utilized to harness the biological wealth for societal and economic benefit of the country on an environmentally sound basis.

The Department has initiated several important programmes relevant to national needs and priorities. The major initiatives have been taken to establish National Centre for Plant Genome Research (NCPGR), National Brain Research Centre (NBRC), National Bioresource Development Board (NBDB), Programmes on functional genomics, sequencing of silkworm genome and chromosome 11 in rice, and leishmania have been initiated. *Jai Vigyan* missions on vaccines, genomics, databases and herbal products are some other important projects. Revised guidelines for transgenic plants for research and development have been laid down. National Facility for Containment and Quarantine of Transgenic Plants, approval for large-scale field trials of insect

resistant cotton by private sector and several other transgenic research leads would contribute towards agriculture and plant science areas. The work of Patent Facilitation Cell, International Depository Authority for Microorganisms, National Facility for Diagnosis of Viral Disease of Tissue Culture Planting Material, programmes on bioprospecting for biological molecules, molecular taxonomy and Integrated Nutrient Management have progressed well. R&D leads have been pursued for technology transfers. Biotechnology programmes for societal benefit have been focussed for the service of target population in rural areas particularly women, SC/ST and weaker sections. A Women's Biotechnology Park and a Biovillage have been set up. Human resource development continues to be a priority.

An important effort has been the creation of awareness amongst industries, State Governments and financial institutions about the importance of biotechnology. Several states are setting up institutional framework, Departments of Biotechnology, Biotechnology Parks, Advisory structures, Centres of Excellence etc. Many small and large industrial houses have come forward to develop new partnerships. International collaboration is providing rich dividends.

Salient Achievements

Product and Process oriented biotechnological research and development for application in agriculture, health sector and industry for the benefit of society have been given a major thrust. R&D and demonstration programmes have been supported in different fields based on the advice of Expert Task Forces in different areas.

Basic Research and Emerging Areas: Basic research programmes in modern biotechnology have been supported to provide new vistas to the knowledge required for understanding the intricacies involved in any applied research. Support to basic research through R&D projects has been vital to develop expertise and investigating basic biological processes for future applications. Programmes on protein engineering, drug and molecular design, identification potential molecules for development of vaccines and diagnostics for infectious diseases have shown promising results. An Indian patent has been filed for a highly efficient and cost-effective process for the preparation of large quantity (300-400 mg) of pure (native-like) recombinant streptokinase. Patent applications have also been filed for rapid method for immobilization of biomolecules and Enzyme-Linked Immunosorbent Assay.

Plant Biotechnology : Concerted efforts have been made to promote and strengthen the area of agricultural biotechnology. The programmes are directed to major problems of identified priority crops, development of transgenics for both quality and quantity improvement and basic research in the area of plant molecular biology. An initiative has been taken by the Department to join the International Rice Genome Sequencing programme with a commitment to sequence 10 Mb of chromosome 11 in a period of five years. Development of markers for high quality protein content and cloning/modification of triticin gene with enhanced lysine content in wheat, development of molecular methods for hybrid seed mustard, production of transgenic plants of tobacco with viral resistance are some of the other important achievements. Transgenic pigeonpea, chickpea and tomato resistant to insects are ready for evaluation and transgenic mustard is to be field evaluated for male sterility restoration studies and herbicide resistance.

Biofertilizers: A number of projects have been implemented with an objective to develop integrated nutrient packages for different cropping systems in various agro-climatic zones of the country and development of transgenic efficient strains of inoculants and technology for mass production of biofertilizers. Under the network programme on integrated nutrient management, several packages have been developed and tested for field applications at 17 centres across the country.

The experiments will facilitate judicious application of chemical fertilizers and adoption of microbial inoculants for various cropping systems. Eleven thousand trials and demonstrations have been conducted, benefiting 19000 farmers. Technologies for large-scale production of mycorrhizal and rhizobial biofertilizers have been transferred to four industries.

Biological Pesticides: An R&D network programme has been supported for developing a package of practices which is cost effective, sustainable and eco-friendly in different crop eco-systems for control of pests, diseases and weeds of important crops across the country. Under the Integrated Pest Management, an area of 65,000 hectares has been covered in different agroclimatic zones, benefiting more than 30,000 farmers so far. Biopesticide formulation technologies have been transferred to the industry.

Animal Biotechnology: The Department has provided support for various programmes on animal health, diagnostics, animal byproducts, genetic characterization and transgenics, with the overall objective to enhance the productivity in animals through advanced techniques. Promising leads have been obtained on indigenous breed characterization and embryo preservation. Embryo transfer technology was perfected in cattle and 1000 genetically superior calves were born including 100 buffalo calves. Embryo transfer technique in camel was standardized and a new protocol for camel superovulation was developed for the first time. Transgenic mice carrying antibiotic markers, Hepatitis-B antigens, inter-leukin genes and other markers have been developed. A new rabies vaccine for animals has been produced and is being tested for technology transfer.

Aquaculture and Marine Biotechnology: A number of programmes have been supported for development of transgenic fish, bioactive components from marine sources and improved



Bunnies produced through nuclear transfer.

production of both fish and feed. Demonstration projects have been implemented for grow-out operations, hatchery and feed mill development for prawn. This has benefited a large number of farmers and entrepreneurs. A record production of over 10 tonnes/ha/yr in two crops of prawn has been achieved through semi-intensive aquaculture. Through intensive crop farming, production level of 18 tonnes/ha/yr has been achieved. An indigenous feed has been developed and tested for prawns. Genomic libraries of carps were constructed. A vibrio based vaccine against white spot disease in prawn is ready.

Plant Tissue Culture: The Department has been supporting programmes on plant tissue culture with the main objective of developing regeneration protocols of economically important forest trees,



Synchronous fruiting of banana plants raised through tissue culture.



Tissue culture raised sugarcane – hardened plants in polyhouse.

horticulture, and plantation crops. A total of 20 protocols for regeneration have been developed. Field performance was tested for the tissue culture raised plants in a number of plantation crops (tea, coffee and pepper). Molecular diagnostic kit has been developed for detection of Bunchy Top Virus in Banana.

Micropropagation Technology Parks: Micropropagation Technology Parks at NCL, Pune and TERI, New Delhi are serving as a platform for transfer of proven technologies and training in tissue culture. So far 6.5 million plants have been produced and planted in 7500 hectares in 17 states. Technologies for 10 species have been transferred to the industry. A satellite park has been set up in the north-eastern part of India for popularization of technology and production of planting material for the region. Regional hardening units have also been set up for different agro-climatic regions.

Bioprospecting and Molecular Taxonomy: A Network programme on Bioprospecting and Molecular Taxonomy has been implemented for characterization and cataloguing of the economically important plant species, using molecular markers, with focus on the two hot spot regions and prospecting of the genes and molecules of bioindustrial importance. The biome mapping of five North-Eastern states and three states of the Western Ghats has been successfully carried out by the Department of Space. A total of nine stress tolerant genes have been identified from plant species. A cold tolerant gene from plant species from Himachal Pradesh has been isolated. A salt tolerant gene has also been identified and cloned in a mangrove. Bioactive molecules having biocidal activities have been isolated and characterized from seven plant species.

Under the programme on molecular taxonomy, molecular characterization of millets, legumes and endemic species of Eastern Ghats is being carried out.

Seri-biotechnology: A number of projects on biotechnology for improving the productivity and quality of silk, along with the improvement of the host-plants in both mulberry and non-mulberry sericulture, are in progress. The silkworm genome initiative has provided some leads. Triploid mulberry plants have been field evaluated. Putative transgenic mulberry plants are being multiplied for further analysis.

Medicinal and Aromatic Plants : Biotechnological

interventions for conservation, micropropagation, production of secondary metabolites, biotransformation of intermediates into pharmaceutically important products and genetic improvement have proved to be very useful. Immunomodulator compounds from *Piper longum* have been identified and a patent filed in India/ USA for the process and product. The technology has been transferred to industry. Four Gene Banks have been set up for conserving collected accessions of rare, threatened, endangered and economically important species of medicinal and aromatic plants.



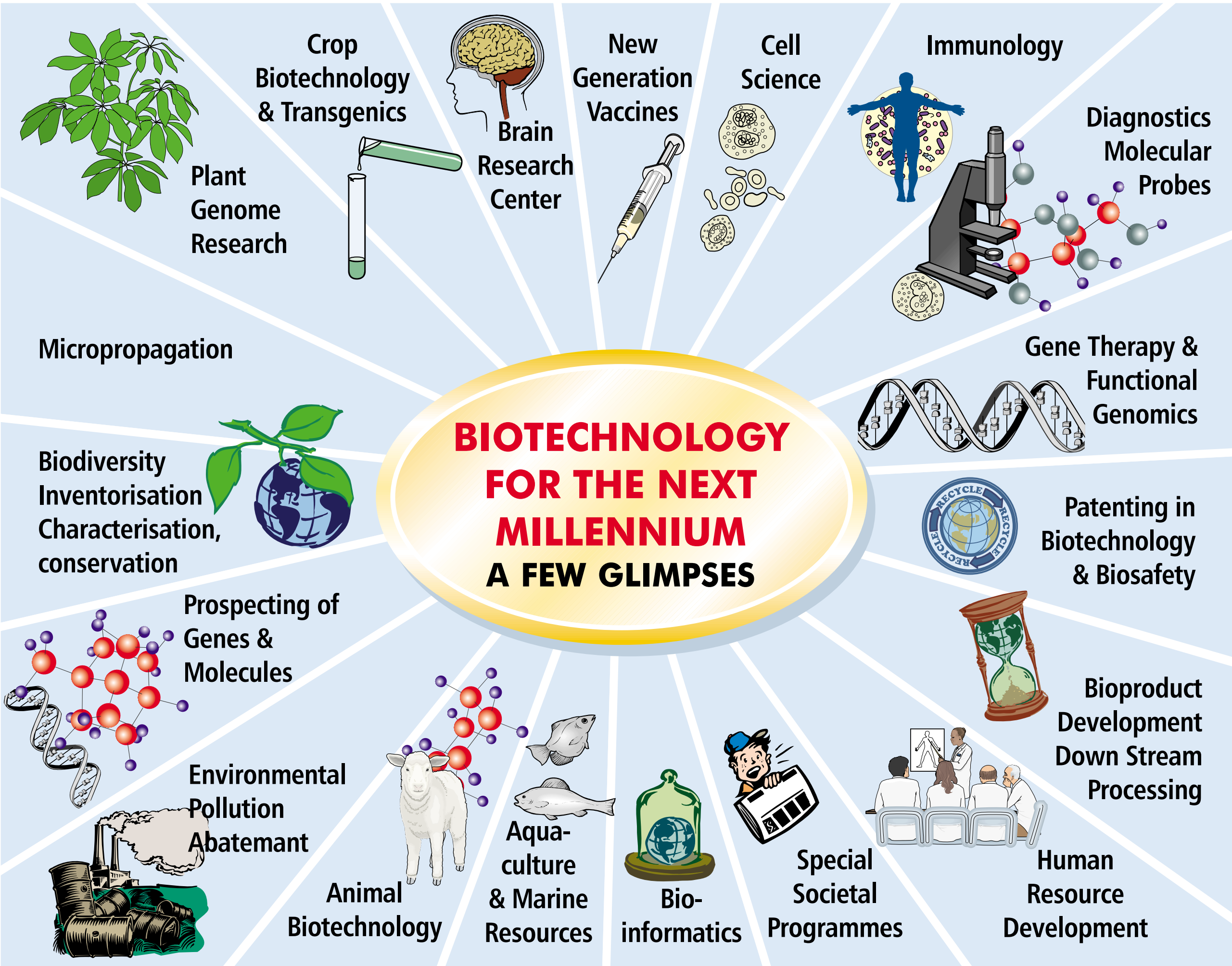


Top: Cocoon rearing for sericulture by rural women. Bottom: Cultivation of medicinal plants in Himalayas.

Biodiversity Conservation and Environment: A number of programmes have been supported for developing environment friendly technologies through the application of biotechnological tools. Ecological restoration technology for revegetating limestone quarries has been successful in Mussoorie and Delhi region. The crude oil and oil sludge degrading bacterial consortia namely "OIL ZAPPER" has been successfully demonstrated. The technology packages have been transferred to the Industry for commercial exploitation.

Protocols for collection, evaluation, propagation and reintroduction of 15 mangrove species have been standardized. Over 5000 micropropagated plants were transplanted in semi-natural habitat after hardening. A collaborative proposal on "Conservation of Endangered Animals", has been supported to work on the Asiatic lion and tiger and establish a gene bank, and a semen bank.

Medical Biotechnology: The main objective of the programme is development of diagnostics, new generation vaccines for prophylactic and therapeutic use, drug delivery systems, production of important biological/ biomolecules, and close interactions with industries for transfer of technologies. Research projects were implemented in the areas of major infectious and non-infectious diseases viz. tuberculosis, HIV, malaria, leishmaniasis, cholera, *Helicobacter pylori*, dengue, typhoid, cancer, heart diseases and contraceptive vaccine. Projects on oral cancer and clinical applications of the stem cells have been initiated. Three diagnostic kits for detection of



HIV-I & II, a therapeutic vaccine for leprosy, the Leprovac, as an immunomodulator and a drug delivery system for systemic fungal infections have been developed and transferred to industry. Two hepatitis C diagnostic tests and a prototype vaccine for rotaviral diarrhoea have been developed and validated. Special projects for development of edible vaccines for rabies and cholera are in an advanced stage. Eight test systems for diagnosis of dengue, hepatitis and reproductive hormones have been transferred to the industries.

Human Genetics and Genome Analysis: The Human Genome Project has ushered in a new era of genomics. The technological developments that have taken place since the initiation of this international mega project have provided opportunities for a big leap in the area of human genetics and genome analysis. Several programmes were initiated in the area of Human Genetics & Genome Analysis during 1990-91, with the main aim of providing genetic diagnosis and counselling to families with genetic disorders, to develop new methods for diagnosis of such disorders; and to find out the functions of the genomic DNA sequences. For this purpose fourteen genetic clinics were established for providing molecular diagnosis and counselling for the common genetic disorders such as beta-thalassemia and other haemoglobinopathies and Duchenne Muscular Dystrophy (DMD) prevalent in the country. About 13,845 affected families have benefited from these units so far.

A number of programmes have been identified through expert level consultations for developing

projects related to the Post Genome Era. Action has been initiated to further strengthen the areas of functional genomics, proteomics, pharmacogenetics, custom made drug designing, development of molecular diagnostic methods for various infections, genetic disorders and targets for drug development.

In the programme on functional genomics started a few years ago, powerful computational capability for handling large-scale human genome sequence data, robotic methodologies for genotyping and PCR based diagnostics for common genetic disorders have been developed.

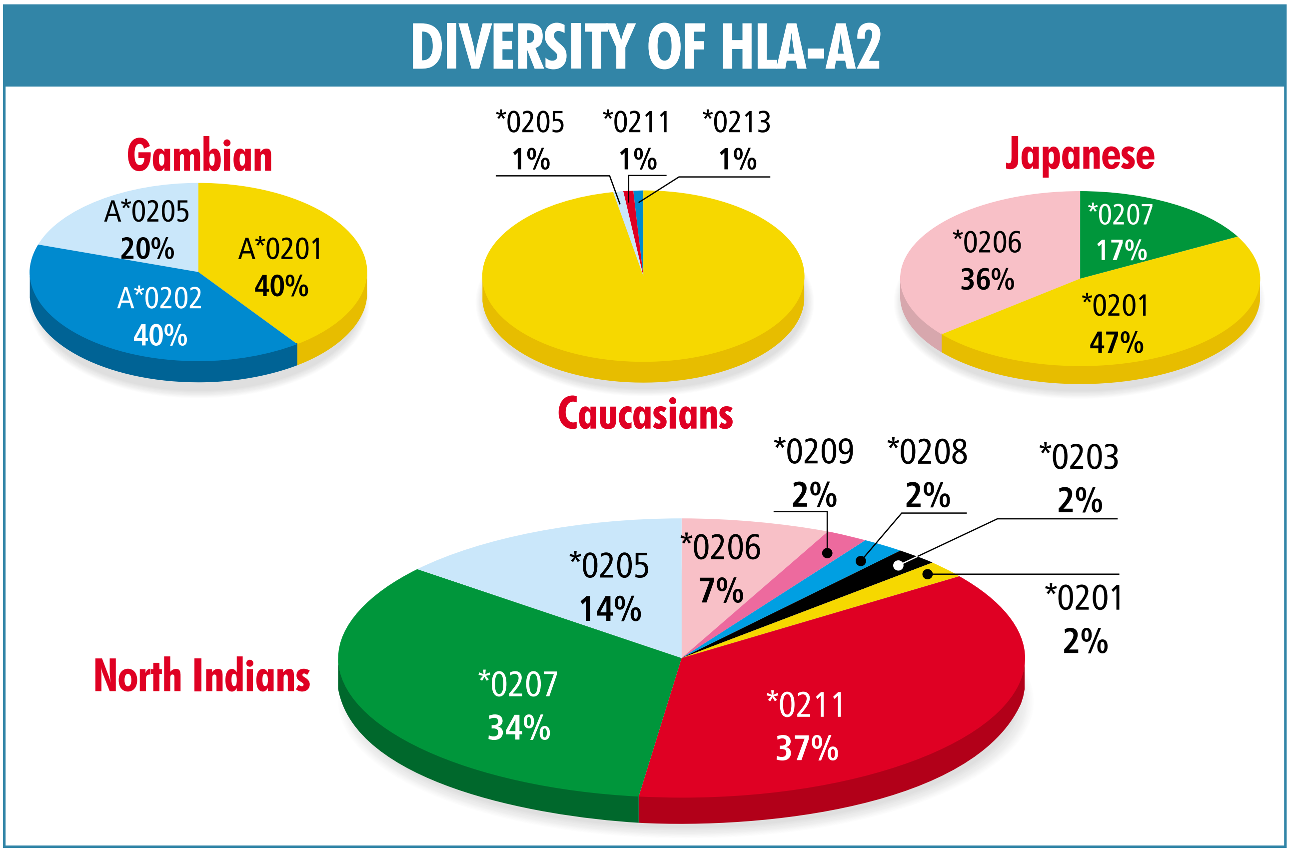
Bioethics: The Department has set up a National Bioethics Committee to consider the issues related to the universal declaration on human genome and human rights and to liaise with the International Bioethics Committee of UNESCO.

Food Biotechnology: In the area of Food biotechnology low cost nutritious food has been developed for providing high energy to children. The National Dairy Development Board, Anand undertook pilot plant process standardization for the production of 'Soft Chikki'. Eighty pilot product trials were carried out and various processing conditions were standardized. Other projects such as 'Dal analogue"' made out of edible grade defatted soyflour and wheat flour resembling the ordinary 'dal' with similar cooking properties and containing 35% more proteins has been developed.

Jai Vigyan National S&T Missions

The Department has launched four Jai Vigyan National S&T Missions in the area of development of new generation vaccines, biotechnology for herbal product development, coffee improvement and establishment of mirror sites for genomics. There have been several leads:

The main objectives of the New Generation Vaccines Development mission are to study the efficacy of DNA, recombinant/ peptides vaccines



for cholera, malaria, tuberculosis, Japanese encephalitis (JEV) and rabies (for animals); develop preventive/ therapeutic DNA candidate vaccines. A DNA based vaccine for JEV using NI1 and NS 3 enveloped proteins has been developed.

The Herbal Product Development Programme aims at (a) developing improved ergot production technology, (b) agro technologies for high yielding *Artemisia annua*, (c) therapeutic applications of a compound isolated from *Tinospora cordifolia,* (d) developing herbal product for hyperlipidemia, and (e) developing immuno modulatory and anti-arthritic agents of herbal origin. Field experiments are underway on *Jeevan Raksha* variety of *Artemisia annua* indigenously developed to yield 20 to 80 kg of artemisinin/ha with a view to further improving the yield.

A network programme on Coffee Improvement through Biotechnological approaches has been supported with two major objectives: germplasm characterization, mapping and cataloging and genetic transformation for improved varieties resistance to disease and pests and also with low caffeine content. A complete regeneration system has been developed for arabica and robusta coffee through various explants. Protocols have also been standardized for embryo rescue from distant crosses. A simple working protocol has been developed to extract high molecular weight genomic DNA from leaf samples of coffee.

Several internationally recognized databases have been established in India under the National Jai Vigyan Science & Technology Mission for Genomic Research at: The Indian Institute of Science (IISc), Bangalore; University of Pune, Pune; Jawaharlal Nehru University (JNU), New Delhi; and Institute of Microbial Technology (IMTECH), Chandigarh. The Databases will be in the form of Mirror Sites, such as Genome Databank (GDB), Protein Database (PDB), Plant Genome Databases and Databases and Software hosted at European Bioinformatics Institute (EBI).

Technology Transfer

Approximately 40 technologies have been transferred to different industries. These include, diagnostic kits for HIV, Hepatitis, Dengue, assessment of reproductive hormones, Japanese Encephalitis, Vaccines for leprosy, drug formulation for septic shock, plant tissue culture protocols, formulation of biofertilizers, high protein gene from *Amaranthus* and bioremediation technology for mine spilled dumps and crude oil spillage.

Biosafety and IPR

The Department with the help of senior scientists and experts has evolved very effective biosafety guidelines which have been widely circulated across the country. A three tier biosafety mechanism has been created- Institutional Biosafety Committee (IBSC), Review Committee on Genetic Manipulation (RCGM), and Genetic Engineering Approval Committee (GEAC).

A Biotechnology Patent Facilitating Cell has been established with the objective of creating awareness and understanding relating to patenting.

Bio-Medical Technologies Transferred and Launched in the Market

Technology	Developed By	Launched By
Leprosy immunomodulator	NII, New Delhi	M/s Cadila Pharmaceuticals, Ahmedabad
Leshmaniasis detection kit	CDRI, Lucknow	M/s Span Diagnostics Ltd., Surat
Western Blot for HIV-I & II	CRI, Mumbai	M/s J.Mitra & Co., New Delhi
Naked Eye agglutination System for HIV-I & II	University of Delhi, South Campus	M/s Cadila Pharmaceuticals, Ahmedabad
Hepatitis C Diagnostics ELISA Based	ICGEB, New Delhi	Xeytron, Bangalore

Bio-Medical Technologies Transferred (not yet launched)

S.No.	Technology	Developed by	Transferred to
1.	The 1gM Mac ELISA for the detection of Dengue	NIV, Pune	Zydus Cadila Health Care, Ahmedabad
2.	The 1gM Mac ELISA for the detection of Japanese Encephalitis	-do-	-do-
3.	The 1gM MacELISA for the detection of West Nile	-do-	-do-
4.	ELISA system to measure alpha-feto protein levels in pregnant women	IICB, Kolkata	M/s Shantha Electronics, Hyderabad
5.	An 1gM based system for the detection of Hepatitis A virus using monoclonal/polyclonal antibodies	NIV, Pune	M/s Bharat Biotech.Ltd, Hyderabad
6-9	Urine based systems (ELISA) for the detection of four Reproductive Hormones i.e.(PDG) Pregnandiol Glucuronide Oestrogen Glucuronide (EIG), Folicle Stimulating Hormone (FSH) & Luteinizing Hormone (LH) (four separate systems)	IRR, Mumbai	Zydus Cadila Health Care, Hyderabad
10.	A technology utilizing Yarrowia liplytica expressing Hepatitis E surface and pre S genes (yielding high level of proteins/single step purification)	University of Baroda, Baroda	Biological Evans Ltd., Hyderabad
11.	A technology for expressing hCG using Pichia pastoris system	IISc, Bangalore	Cadila Pharmaceuticals, Ahmedabad

So far 90 patents have been filed by the Department. A patent database has also been prepared.

Biotech Facilities and Centres of Excellence

The Department has supported a large number of facilities, repositories, and Centres of Excellence across the country. Nineteen such facilities so far established have an overall objective of facilitating research and providing services across the country.

An International Depository Authority has been recently set up at IMTECH, Chandigarh for Conservation of Microbial Biodiversity in accordance with the Budapest Treaty. Other new facilities established are the National Containment Facility for Transgenic Plant Material and the National facility for Virus Diagnosis and Quality Control of tissue culture raised plants at IARI, New Delhi.

Bioinformatics

Biology has become more computationally intensive. Bioinformatics has acquired significance owing to its potential applications for identification of useful genes, leading to the development of new gene products, drugs and diagnostics. The Department has expanded the bioinformatics network in the country for easy access and dissemination of data information resources through its distributed information centre; establishing International databases; establishing new centres; and training. Fifty five centres, established under the BTIS net are continuing to serve these objectives. Six interactive computer graphic facilities and four diploma courses in Bioinformatics have made commendable progress.

Human Resource Development

The main focus of the HRD programme supported by the Department has been to generate large numbers of highly trained scientists/students. The Department has supported programmes in 51 universities across the country. The main programmes being supported are PG/PD/one year diploma courses. The approximate annual intake of the students is 500-600. The Department has recently initiated a restructured post-doctoral fellowship programme. Biotechnology Associateships are offered - both national and overseas - to train scientists in the fron-

Technologies under Negotiation

S.No.	Technology	Developed by
1	LDH based ELISA for Malaria	CDRI, Lucknow
2	DAT for Toxoplaenosis	AIIMS, New Delhi
3	Reagents for thyroid and steroid hormones	AIIMS, New Delhi, IICB, Kolkata
4	Peptide based ELISA system for protection of HIV-I & II	NII, New Delhi
5	Skin culture technology for use in burn cases	NCCS,Pune
6	Medium for preservation of Cornea	NCCS, Pune
7	Haemagglutination for Kala-azar	CDRI, Lucknow
8	IFA for Rabies	AIIMS, New Delhi
9	Systems for Steroids	IICB, Kolkata
10	Tests for Species Specific Snake Bite	VM Scientific Research Foundation, Bangalore

tier research areas of Biotechnology and also for upgrading the knowledge in advanced areas of research. Short-term, long-term and industrial training programmes are also being supported for mid-career scientists to enhance their career opportunities. Numerous awards have been instituted at all levels to recognize and encourage excellence. These include Biology Scholarships for college students, National Bioscience Award for Career Development for mid-career scientists, a National Woman Bioscientist Award and a Biotech Process Development Award. A Biotech Chair has been instituted in honour of G.N.Ramachandran, at IISc, Bangalore.

International Linkages

A new direction has been given to the ongoing international bilateral and multilateral cooperation. A number of programmes of S&T priority of national interest have been identified/implemented for further collaboration with developed and developing countries. These are focussed on issues of national concern such as human reproduction, environment, genetic disorders, agriculture, health and industrial applications. Programmes have been established with Belarus, China, Cuba, France, Germany, Israel, Italy, Japan, Myanmar, Poland, Russia, Sri Lanka, Sweden, Switzerland, Tunisia, UK, USA and Vietnam. Interactions have also been initiated with S&T agencies in Australia, Hungary and the Philippines. Multilateral collaborations involve countries of SAARC, G-15 and the ASEAN.

Autonomous Institutes

The Department has established a number of autonomous institutes with the objective of carrying out excellent work in highly relevant areas and provide leadership in selected areas.

National Institute of Immunology (NII), New Delhi: NII was set up by DST at a time when immunology as a discipline was at its infancy in the country. It was later transferred to DBT and has presently developed into a centre of excellence. Researches carried out here have yielded several products and innovations for which one Australian, two American and one Canadian patents have already been granted. Over 150 research papers have been published on gene regulation, molecular mimicry, reproduction and development as well as immunity and infection.

National Centre for Cell Science (NCCS), PUNE.: The NCCS which started as a National facility for animal cell and tissue culture has broadened its goals from a repository into a Research and Development Centre. Beginning with over 100 odd cell lines at the time of its inception, it presently has 1000 various cultures and hybridomas. Over 200 researchers from across the country have been trained so far. The efforts of NCCS have resulted in the development of biocompatible synthetic matrices suitable for controlled drug release and immuno

Bioinformatics, Infrastructure and HRD Programmes of DBT



isolation of islet cells. The centre has started three skin culture and production centres across the country.

Centre for DNA Fingerprinting and Diagnostics (CDFD), Hyderabad: CDFD is handling cases of DNA fingerprinting received from crime investigation agencies and the judiciary in the country, and also specimens sent by international agencies such as Interpol, Governments of Bangladesh, New Zealand, Australia. The Centre started a screening programme for diagnosing inborn errors of metabolism among the new born babies. The Centre provides genetic counselling to the families and follow up services to affected children. The automated genome facility of the Centre has synthesised more than 820 oligonucleotide primers for service and R&D uses. Over 800,000 nucleotides have been sequenced during the last year as part of the efforts to characterise mutations, genetic susceptibility factors and molecular epidemiology.

National Centre for Plant Genome Research (NCPGR), New Delhi: The Centre started functioning with effect from 1 April, 1998. It is utilizing molecular biology approaches alongwith tissue culture and genetic engineering technology to identify important genes and manipulate them for generating transgenic plants with improved agronomic traits and pathogen/stress resistance. A novel gene, *AmA1* from *Amaranthus hyprochondriacus* has been used for generating transgenic plants of agronomic importance. Transgenic potato with high nutritional quality has been developed with the introduction of *AmA1* gene. The technology for over expressing *AmA1* in the yeast cell system has been transferred to Cadila Pharmaceuticals for industrial production of animal feed supplement.

National Brain Research Centre (NBRC), New Delhi : NBRC was established in 1999 with the main aim to undertake, aid, promote, guide and coordinate research of high calibre in basic and clinical neuroscience and to encourage and augment effective linkages between various scientific and research agencies/laboratories and other organizations working in the field of brain research.

Institute of Bioresources and Sustainable Development (IBSD), Imphal: The Department is in the process of establishing the Institute of Bioresources and Sustainable Development in the North-Eastern region of India at Imphal with the objectives of development of bioresources and their sustainable use through biotechnological interventions for the socio-economic growth of the region.

National Bioresource Development Board (NBDB)

NBDB has been set up with the main purpose of developing a broad policy framework for effective application of biotechnological and related scientific approaches for R&D and sustainable utilization of bioresources. Two broad groups of activities have been identified: (a) preparation of digitized inventories of plant, animal, microbial, and marine resources, and (b) R&D projects, programme support, establishment of centres of excellence, training and demonstrations, for the development of bioresources of north-eastern region, Himalaya, coastal and island ecosystems, deserts, Indo-Gangetic plain and Peninsular India.

Biotechnology for Societal Development

Several special biotechnological programmes for the benefit of underprivileged (SC/ST population, women and rural people) have been implemented in the areas of biopesticides, biofertilizers, vermicompost and vermiculture, sericulture, floriculture, mushroom cultivation and medicinal plant production, poultry and fish farming and improvement of human health. Universities, national laboratories, state government institutions, krishi vigyan kendras and NGOs have been involved for implementing these projects. 52,000 families have been trained in various biotechnology related areas through 102 projects.

A Biovillage has been established at Mocha, near Porbandar in Gujarat for extension of technologies which are pro-poor, pro-women and pro-nature to the grassroot level. A Women's Biotechnology park has been established in Chennai. It aims to provide opportunities to professionally qualified women for setting up self-employment ventures using various biotechnologies. The park has twenty industrial modules and an equal number of land modules for agro-biotechnology activities.

Development of Biotechnology

During the last two years, with revolution in information technology, awareness regarding utilization of biotechnology potential has increased many-fold. As a result several State Governments are formulating proposals, particularly for establishing Biotechnology Parks, Biotechnology City/ Knowledge Parks etc. The Department is providing scientific and organizational advice to the states in these endeavours.

Major achievements of the Department in terms of research leads, products and technologies other than those already mentioned are given below:

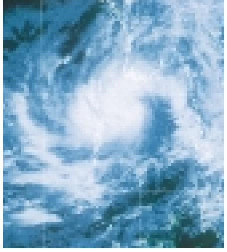
Research leads

- Three dimensional structure of Lactoferritin determined and the protein used as anti-bacterial or anti-fungal agent.
- A novel target gene delivery system dedicated for liver cells developed and patented in USA.
- Identification of mutation conferring resistance to HIV infection in Indian population.
- Cloning and sequencing of at least six genes achieved, specially for the seed storage protein, amino acid biosynthesis and genes for plant defense and for enhancing the nutritional quality. A US Patent has been granted for the seed storage protein gene.
- Genes encoding for two endotoxins designed, chemically synthesised and successfully assembled, to be used for transformation in important crops.
- Three major fruit ripening genes of banana have been cloned at NBRI, Lucknow.
- By using polymerase chain reaction (PCR), three genes for quality traits in wheat have been identified at the Punjab Agriculture University, Ludhiana, Department of Agricultural Botany, Ch. Charan Singh University, Meerut, and Department of Biotechnology, GBPUT&A, Pantnagar.
- A cold resistant gene has been identified from a plant of the cold desert region as part of the bioprospecting of biological resources at the IHBR&T, Palampur.
- Transgenic silkworm with luciferase gene produced. The mori silkworm larvae can act as bioreactors for producing proteins of agricultural and therapeutic importance.
- For transfer of targeted genes into silkworm (*Bombyx mori*), a system using *Bombyx mori* nuclear polyhedrosis virus (BmNPV) has successfully demonstrated the expression of ORF-3 of Hepatitis E viral antigen at the IISc, Bangalore.
- A process for degumming of silk with fungal proteases (enzymatic treatment) has been developed as an alternative method for improvement in the quality of fabric.
- After successful cloning and expression of glycoprotein-2 and 3 of dog zona pellucida in *E.coli*, these recombinant products have been evaluated for their implication in regulating fertility in female dogs at the Central Military Laboratory, Meerut.
- A Pregnancy Diagnostic Kit in cattle and buffalo using milk as the test material is being refined to increase sensitivity and specificity.
- Vaccines against fish pathogens (*Aeromonas sp*.and *Pseudomonas sp*.) have been developed.
- A highly effective agent for inducing fish spawning developed.
- Hylauronic acid as a marker for infertility in male has been assessed at JNU, New Delhi.

- First indigenous recombinant vaccine strain for oral cholera, VA 1.3, and Rotaviral diarrhoea enter clinical trials.
- A Network programme on human genome diversity was initiated to assess the linkages of different tribes/ castes and to identify genes responsible for diseases/ disorders.

Technology Transfers & Demonstrations

- A total of 40 Technologies transferred.
- Five technologies for large-scale production through tissue culture transferred to industry.
- Tissue culture of vanilla plants are under demonstration in the states of Kerala, Karnataka and Tamil Nadu. Elite tissue culture of greater cardamom (*Amomum*) is under demonstration in Sikkim.
- Tissue culture-raised lesser cardamom (*Elettaria cardamomum*) demonstrated in 100 ha; 40% increase in the yield achieved.
- Biobeneficiation and desulphurization technologies perfected and transferred to industry
- Bioremediation field tested for wasteland recovery; more than 50 acres land recovered with biomass.
- Cost effective, environmentally sound bacterial isolates identified and demonstrated to industry for crude oil remediation.
- Immunodiagnostic kits for detection of pebrine disease and Nuclear Polyhedrosis Virus (NPV) in mulberry silk worm successfully used.
- Tissue culture based vaccines for poultry being transferred to the industry.
- An isoquinoline alkaloid was isolated from *Berberis aristata* which showed potency in preventing systemic infection leading to septic shock, tissue damage and organ dysfunction in burn cases has been transferred to Industry.



CHAPTER XXXIII

MINISTRY OF ENVIRONMENT AND FORESTS

The pressing need of the hour for India was social and economic development upon attaining Independence. Vigorous programmes were mounted to achieve the goals of modernisation and self-reliant industrial growth. Technology and its extensive application was the basic tool for effecting such a transformation and this was put to use to accomplish the mission.

However, as the years passed, the world as well as India realised that application of science and technology, without assessing its far reaching and global consequences, posed progressively greater threats to the planet's environment. It is ironic that the very science and technology which warns us of the present danger should, in a large part, have been responsible for bringing us to this pass!

In order that development proceeds without destruction and that environmental considerations are incorporated into the planning process itself, the Government of India established a separate Department of Environment in 1980, and elevated it to the Union Ministry of Environment and Forests in 1985. This was the culmination of the process set in motion by then Prime Minister, Indira Gandhi, in 1972 after her participation in the Stockholm Conference on Human Environment.

> "…the environment cannot be improved in conditions of poverty, unless we are in a position to provide employment and purchasing power for the daily necessities of the tribal people and those who live in around our jungles, we cannot prevent them from combing the forests for food and livelihood; from poaching and from despoiling the vegetation. How can we speak to those who live in villages and slums about keeping the oceans, the rivers and the air clean when their own lives are contaminated at the source?"
>
> -- *Indira Gandhi, Stockholm Conference, 1972*

The Mandate of the Ministry includes: conservation and survey of flora and fauna; forests and wildlife; prevention and control of pollution; afforestation and regeneration of degraded areas; and protection of the environment. These tasks are being pursued by the Ministry through environment impact assessment of development activities, eco-regeneration programmes, assistance to organizations implementing environmental and forestry programmes, promotion of environmental and forestry research, education and training to augment the requisite humanpower, dissemination of environmental information, international co-operation and creation of environmental awareness among all sections of the population.

Ever since the Ministry of Environment and Forests was set up, India has built up capabilities in almost all sectors of environmental management, including those of legal instruments, human resource development, promotion of R&D and setting up of institutions.

The legislative and regulatory measures which have been developed aim at preservation, conservation and protection of the environment. Some important legal instruments are:

- Wildlife (Protection) Act, 1972
- Water (Prevention and Control of pollution) Act, 1974
- Forest Conservation Act, 1980
- Air (Prevention and Control of pollution) Act, 1981
- Environment (Protection) Act, 1986
- Public Liability Insurance Act, 1991
- National Environment Tribunal Act, 1995
- National Environment Appellate Authority Act, 1997.

Besides these, a number of policy statements were evolved, such as a National Conservation Strategy and Policy Statement on Environment and Development 1992, a Policy Statement on Abatement of Pollution, 1992 and National Forest Policy, 1988. In addition, several notifications have been issued under EPA 1986, with respect to siting of polluting industries, coastal area regulation, and handling of genetically modified organisms (GMOs), hazardous waste management and handling etc.

As part of promotion of R&D, the Ministry has set up a network of autonomous and other institutions which carry out original work and also offer expert and specialist advice in respective areas. These include:

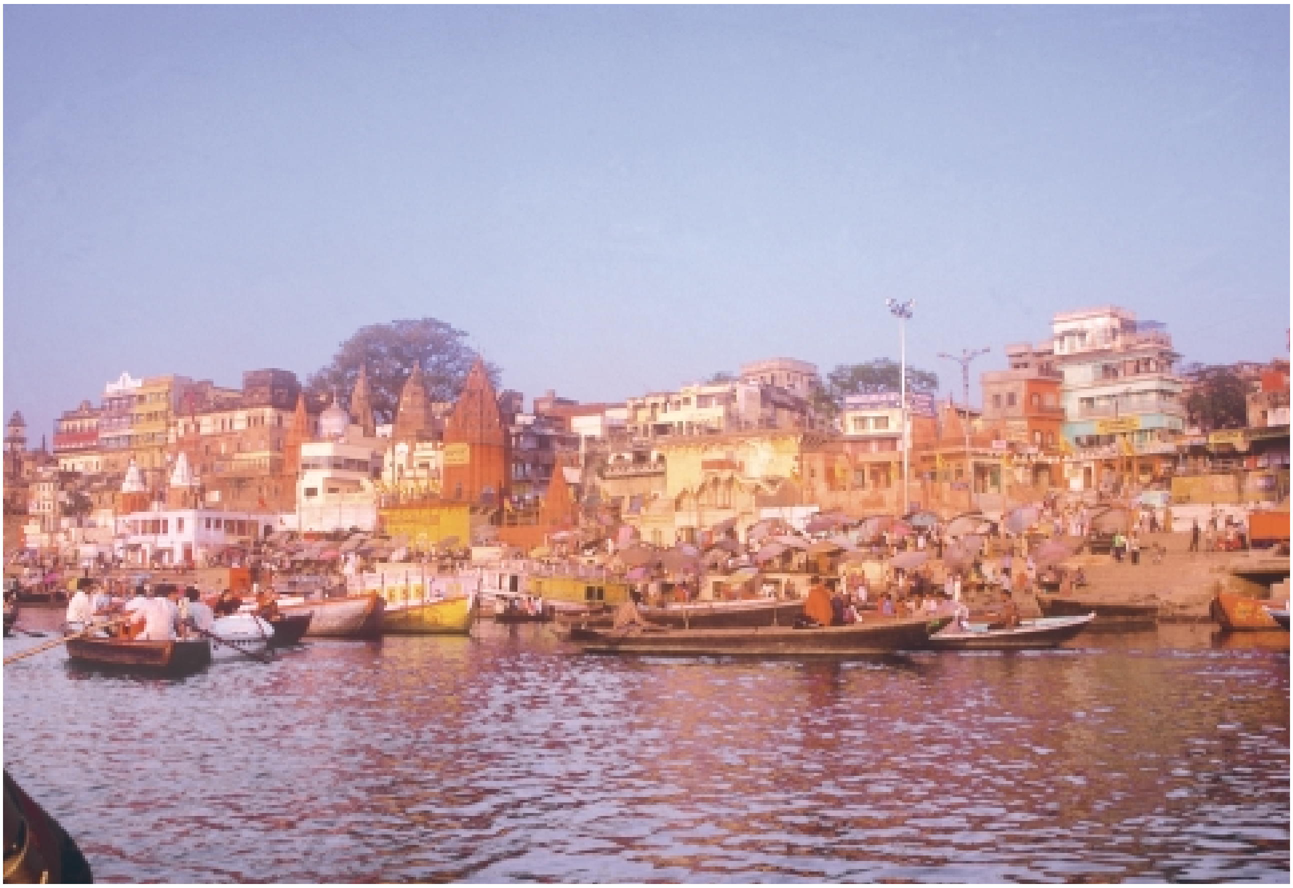
- Indian Council of Forestry Research and Education, Dehra Dun
- Wildlife Institute of India, Dehra Dun
- G.B Pant Institute of Himalayan Environment and Development, Kosi-Katarmal, Almora, UP
- Centres of Excellence in Environmental Education: Centre for Environment Education, Ahmedabad and CPR Foundation for Environment Education, Chennai
- Botanical Survey of India, Kolkata
- Zoological Survey of India, Kolkata
- Forest Survey of India, Dehra Dun
- National Museum of Natural History, New Delhi
- Centre for Mining Environment, Dhanbad
- Centres of excellence in the field of research training in ecology and environment: Centre for Ecological Sciences (Indian Institute of Science, Bangalore); Salim Ali Centre for Ornithology and Natural History (SACON), Coimbatore; Centre for Environmental Management of Degraded Ecosystems, University of Delhi, Delhi
- Tropical Botanic Garden and Research Institute, Thiruvananthapuram, Kerala.

The Ministry also has established the Central Pollution Control Board, the National Afforestation and Eco-development Board and the National River Conservation Directorate.

> THE PROBLEM OF POLLUTION, FROM ALL SOURCES, HAS RECEIVED THE HIGHEST ATTENTION AT THE MINISTRY OF ENVIRONMENT AND FORESTS.

Dilemmas in pollution: Pollution is not entirely symbolic of industrial and economic development but can also be indicative of poor technologies, poverty and large population. The problem of pollution, from whatever source, has received the highest priority attention at the Ministry.

We are confronted today with rising demands as also the most basic needs of a population growing not only in size, but also in awareness, on the one hand, and a rapid rate of depletion of our natural resource base on the other. Development, aspirations and hopes cannot be put on hold in a democracy. People are impatient with conditions of various kinds of deprivation and rightly expect a better life. It is the duty of the government to respond to these demands. It is true that the world


Photo: H.Y. Mohan Ram

River Ganga at Varanasi (Ghats).

is threatened environmentally, but the prevailing levels of consumption cannot be frozen to condemn the poor societies to perpetual poverty. The space for rise in consumption levels in developing countries can only be provided by restraint on the part of affluent societies accustomed to prodigality. Thus the problems of pollution as also of depleting resources, have to keep in view the people and their numbers, their aspirations, economic standing, literacy, all in the context of international trade and international obligations. Nevertheless, India as a country recognizes the crisis of environment.

India's Environment Action Plan for controlling pollution at the national level calls for the implementation of time-bound programmes that entail coordinated interdepartmental strategies. It envisages control of pollution from various sources such as industrial, domestic, vehicular, agricultural and noise. The basic principle that it seeks to establish is of prevention of pollution, rather than treatment at the end of line and therefore strives for the use of cleaner technologies, appropriate siting of industries, use of cleaner fuels, resource-efficient and energy-efficient technologies, along with regular monitoring of air and water quality, inventorisation and proper disposal of hazardous waste, and above all creation of public awareness. The use of common effluent treatment plants/individual treatment plants for industrial effluents is strongly encouraged through fiscal incentives to industry in terms of custom duty, excise duty, income tax, subsidies and loans for various kinds of positive action, such as purchase and installation of pollution control equipment or processes, recycling and the reuse of waste products like fly ash.

The Central Pollution Control Board (CPCB) monitors water quality of national aquatic resources in 507 stations (out of which 414 stations are on rivers, 25 on ground water, 38 on lakes and 30 are


Photo: H.Y. Mohan Ram

Pine Forest.

on other water bodies like canals, creeks, drains and ponds) and ambient air quality in 290 stations (covering 90 cities/towns in 24 states and five union territories). Air and water quality standards for different areas/uses have been notified.

Attempts to develop and use low-pollution fuels led up to the use of lead- free petrol and of CNG in public transport system in Delhi. The air quality has shown a significant improvement.

Forestry: Recognizing the alarming shrinkage of forest cover as revealed by satellite imagery, a high priority has been given to afforestation and forest conservation programmes. The National Forest Policy of 1988 has set a goal of bringing a third of the total land area under forest cover. At present, the forest cover is around 19.4 per cent of the total. The area under dense forest cover is only 12 per cent whereas open forests and mangroves account for 7.4 per cent of the total geographical area. Besides social implications, the heavy denudation of forests has a marked effect on the ecology and the climate of the surrounding areas. Water shortage is a primary result. With the global shortage of energy resources, emphasis has been laid on fast-growing, short rotational trees which could be grown on road sides, along railway tracts, on farm bundings and on other suitable available spaces.

With increasing recognition of the important role that forests play in helping to increase agricultural productivity, to improve rural tribal welfare, to mitigate the impact of energy crisis and in the preservation of the environment, there has been a major shift in forestry development towards these areas of concern resulting in the emergence of new priorities in our forestry sector such as raising of energy and industrial plantations, social forestry, rehabilitation/ regeneration of degraded forests and barren lands including watersheds and environmental protection. This shift has now, however, been matched by the much needed research and development support to cover these new areas of concern and the merging priorities. The forest cover is regularly monitored by the Forest Survey of India and comprehensive *State of the Forest* reports are published. There is good news that deforestation rate per unit population in India is one of the lowest among all the major tropical countries. Further carbon emissions from forests in India are off set by carbon sequestration leading to no net carbon emissions. In order to promote afforestation, Forest Development Agencies have sought to include women's representation and village representation of communities on forest and eco-



Photo: NMNH, New Delhi

Wild elephants in their natural habitat.

development. Committees have been set up in 20 states. A comprehensive long-term national Forestry Action Plan for the next 20 years has been drawn up to mobilize action to achieve the target forest cover of 33 per cent. Eco-task forces of ex-service men have been raised to work in difficult terrains. The earliest institutionalized effort in regeneration, sustainable use and management of degraded forests with the active involvement of the primary stakeholders is the Participatory Forest Management initiated by the State Forest Department of West Bengal in 1972. Following the success of this model, the Government of India has expanded the Participatory Forest Management Strategy to the rest of the country. This is now being implemented by the State Governments in most parts of the country. This strategy is aimed to secure rehabilitation of degraded areas, conservation of biodiversity along with sharing of benefits with local people. Social and economic incentives to rejuvenate and conserve biodiversity are the imporant aspects of the strategy. Also donations from individuals and corporate/non-corporate bodies for regeneration of degraded areas and wastelands are eligible for 100 per cent tax deduction.

Wildlife: The National strategy for wildlife conservation envisages the setting up of a grid of Protected Areas (PAs) representing the various bio-geographic zones of the country. High mountains, coastal and desert areas which are home to endangered species receive 100 per cent funding as PAs. Efforts and appropriate action are kept up to control and regulate trade in wildlife products (inspite of which poaching and illicit trade continue for smuggling ivory, hides and fur), relocate human inhabitations from national parks and sanctuaries to areas outside the demarcations, and increase the area under PAs to 5 per cent of the total land area. At present the total PAs is 4.2 per cent with 490 wild life



Project Tiger

An all-India tiger census conducted in 1967 revealed that there were only 2827 tigers in the country as against an estimated 40,000 at the turn of the last century. Taking this as an indication of the deteriorating health of India's wildness (Tiger is a flagship species), the Government of India launched the Project Tiger in 1973 with the support of NWF-International. In 1993, the tiger population had risen to 3750. A fresh census was started in 1997. It is pertinent to note that it is not just the tiger that has been the beneficiary. Other species such as the swamp deer, elephant, rhino and wild buffalo have received protection through Project Tiger. Some naturalists believe that Project Tiger has also helped in the conservation of natural water bodies on account of preservation of the habitat.

sanctuaries and 88 National Parks covering a total area of 153,000 sq. km representing the major biogeographic provinces of India. The total extent of PAs include 5 designated as World Heritage Sites, 12 Biosphere Reserves (see Table), 6 Ramsar sites for wetlands, besides 27 Tiger Reserves. Additionally, a few more conservation projects have been set up on the Asiatic Lion, the Elephant and the Rhinoceros. A Central Zoo Authority has been created to manage various zoos in the country on more scientific principles. Table shows the data for 1997 when the number of sancturies was 448 and the National Parks 85.

Biodiversity: India is one of the 12 mega-biodiversity countries of the world, the others being Brazil, Colombia, Ecuador, Peru, Mexico, Zaire, Madagascar, Indonesia, Malaysia, China and Australia. With only 2.4 per cent of the global land area, India is home to 7 to 8 per cent of the recorded species of the world. Over 46,000 species of plant and 80,000 species of animals have been so far recorded in the country by the Botanical Survey of India, and Zoological Survey of India, respectively.



Siberian crane at Keoladeo National Park, Bharatpur.

India is an acknowledged centre of crop diversity, and harbours many wild relatives and breeds of domesticated animals.

Liberalization of economy in India in the past few years, coupled with scientific advances in genetic engineering has focused greater interest on the value of biodiversity. However, liberalization also promotes consumerism by throwing ever wider options of products at the consumer. This, in turn, puts pressure on natural resources to meet increasing commercial demand for raw materials and causes faster depletion. In this process, several plant and animal species may soon become extinct

and non-renewable resources exhausted, depriving the coming generations of their benefits.

In spite of the above measures, biodiversity is being depleted due to other reasons such as habitat destruction, use of toxic chemicals (i.e. pesticides, herbicides, toxic wastes) which are fatal to non-target species too. The important steps taken for conservation of species include:

- A grid 16 Biosphere Reserves (BR) have been planned representing all the biogeographic regions of the country. Twelve of these have already been set up and notified.
- National Biodiversity Strategy and Action Plan has been drawn up as a macro-level statement of strategies, gaps and further actions needed for conservation and sustainable use and strategies and realization of actual and potential value of biodiversity.
- A Biodiversity Bill has been introduced in the Lok Sabha, The legislation primarily addresses the issues of access to biological resources and associated knowledge to be permitted to foreign individuals, institutions and of equitable sharing of benefits arising from the use of these resources. It provides for the setting up of a National Biodiversity Authority (NBA). State Biodiversity Boards (SBBs) and Biodiversity Management Committees in local bodies. The bill has been referred to the Department Related Parliamentary Standing Committee on Science, Technology, Environment and Forests for examination and report.
- An exclusive institute on biodiversity is being set up in N-E region of the country.
- National Botanic Garden is being established in Noida near Delhi in addition to strengthening the existing botanical gardens.
- A national project on Capacity Building in Plant and Animal Taxonomy has been launched to fill up the lacunae in our knowledge of the wide variety organisms ranging from animal viruses, archaea, fungi, plants, nematodes, insects and fish and produce trained humanpower in the field of taxonomy. Databases on species are also being built up.



Pelicans (migratory birds from Central Asia).

Environmental Impact Assessment: To ensure that environmental considerations are incorporated in the planning process itself, the following important steps have been taken. Assessment of development projects for their environmental impact has been made compulsory for 30 activities. Public hearing of cases has also been made compulsory since 1997. Environment clearance to projects is given only on the recommendations of appropriately constituted expert committees.

Research Development and Management: The Indian Council of Forestry Research and Education (ICFRE) was constituted in 1986 to oversee and coordinate forestry research in the country. It is the nodal agency for:

- promoting and coordinating forestry education and research.

Biosphere Reserves

Name of the site & area in sq. km.	Location (State) and Bio-geographic zones
Nilgiri (5,520)	Part of Wynad, Nagarhole, Bandipur and Madumalai, Nilambur, Silent Valley and Siruvani hills (Tamil Nadu, Kerala and Kanrnataka) — Western Ghats
Nanda Devi (5,860.69)	Part of Chamoli, Pithoragarh & Almora Districts (Uttaranchal) - West Himalaya
Nokrek (820)	Part of Garo Hills (Meghalaya) - East Himalaya
Manas (2,837)	Part of Kokrajar, Bongaigaon, Barpeta, Nalbari, Kamprup and Darang Districts (Assam) - East Himalaya
Sunderbans (9,630)	Part of delta of Ganges & Brahmaputra river systems (West Bengal) - Gangetic Delta
Gulf of Mannar (10,500)	Indian part of Gulf of Mannar between India and Sri Lanka (Tamil Nadu) - Coasts
Great Nicobar (885)	Southern most islands of Andaman and Nicobar (A&N Islands) - Islands
Similipal (4,374)	Part of Mayurbhanj district (Orissa) - Deccan Peninsula
Dibru -Daikhowa (765)	Part of Dibrugarh and Tinsukhia districts (Assam) East Himalaya
Dehang Debang (5,112)	Part of Siang and Debang valley in Arunachal Pradesh - East Himalaya
Pachmarhi (4,926.28)	Parts of Betul, Hoshangabad and Chindwara districts of Madhya Pradesh,- Semi-Arid-Gujarat Raiputana
Kanchenjunga (2,619.92)	Parts of Kanchenjunga Hills in Sikkim - East Himalaya

- developing and maintaining an internal and national information centre for forestry and allied sciences.
- acting as a clearing house for aid for research and information relating to forests and wildlife.
- developing forest extension programmes and propagating the same through mass media, audio- visual aids and extension systems.
- providing consultancy services in forestry education, research and training.

Besides Forest Research Institute, Dehra Dun, ICFRE has started nine other institutes to carry out research in various parts of the country: Temperate Forest Research Institute, Shimla, H.P.; Tropical Forest Research Institute, Jabalpur, M.P.; Centre for Social Forestry & Rehabilitation, Allahabad U.P.; Centre for Forestry Research and Human Resource Development, Chindwara, M.P.; Institute of Rain and Moist Deciduous Forests Research, Jorhat, Assam; Institute of Forest Productivity, Ranchi, Jharkhand; Institute of Forest Genetics & Tree Breeding, Coimbatore, T.N.; Institute of Wood Science & Technology, Bangalore, Karnataka; Arid Forest Research Institute, Jodhpur, Rajasthan.

The Director-General of forests oversees Forest Conservation, Wildlife, Forest Services (Indian Forest Service Cadre Management, Forest Research, Education & Training; The Indira Gandhi National Forest Academy, Dehra Dun; Indian Institute of Forest Management, Bhopal; Indian Plywood Industries Research and Training Institute Bangalore and Directorate of Forest Education, Dehra Dun.

The role of R&D is crucial in providing the back-up support to the decision making process as also for setting legal standards and improving and developing of eco-friendly technologies. In view of this, R&D projects in identified thrust areas are supported by the Ministry in various national laboratories and universities, with high priority being given to pollution related issues.

Education and Information: For promotion of environmental education and awareness, a number of measures are being taken. Regular interaction is maintained with NCERT and Ministry of Human Resource Development to provide environmental and ecological orientation and inputs in school and university level curricula. The National Museum of



Photo: H.Y. Mohan Ram

The Forest School established in 1878 at Dehra Dun, gave rise to Forest Research Institute (FRI) and colleges in due course. Nestling in the Doon valley with a back drop of Mussoorie hills, FRI is an architectural master piece. FRI and its Colleges emphasize research and training in silviculture, botany, ecology, pathology, entomology, wood anatomy, seasoning, preservation, timber mechanics, timber engineering, chemistry of natural products, cellulose and paper making and minor forest products (presently termed non-wood forest products). Excellent surveys have been done in the field of forest entomology. FRI maintains more than 20,000 authentically named specimens of forest insects. Much work has been done on the control measures, thus saving the precious national forest wealth.

Research carried out by the FRI scientists has resulted in the manufacture of quality plywood, compregnated wood and building boards. The wood seasoning branch of FRI has designed a number of air seasoning sheds and seasoning kilns including vencer dryers. The kiln seasoning schedules have been drawn for all the commercially important species of the country. It has also been possible to (a) classify 200 species of timbers in accordance with their natural durability, (b) to test over a hundred commercial wood preservatives in order to evaluate their efficacy and development of preservatives like Ascu, fire-proof-cum-antiseptic composition and metallic resinates from chir pine resin, and (c) to develop suitable equipment for impregnation of chemicals into timber and methods of treatment of timber, bamboos, canes etc. The paper industry in India depended till recently mainly upon bamboo and sabai grass for its raw material. Knowledge about these resources was an outcome of the researches conducted at FRI. The work done on bagasse (sugarcane waste) has been taken up for commercial exploitation for the production of good quality paper.

Natural History at Delhi and The Regional Museums of Natural History at Mysore, Bhopal and Bhubaneshwar showcase the biological, non-biological resource wealth of the country and reinforce awareness of their value in society. The Centres for Environment Education are being supported at Ahmedabad and Chennai.

The Ministry has set up an Environmental Information System (ENVIS) to collect, collate, store, retrieve and disseminate environmental information relating to various aspects of environment and forests through a network of 25 centres in the country. ENVIS also serves as the National Focal Point of the Clearing House Mechanism of the convention on Biological Diversity in India.

A newsletter of the Ministry, *Environews* reports vaious important policies, programmes, enactments of new legislations/rules, important notifications and other decisions taken by the Ministry from time

Wildlife Sanctuaries and National Parks (1997)

State/Union Territory	Sanctuaries		National Parks	
	Total No.	Area (sq.km)	Total No	Area (sq.km)
Andaman & Nicobar Islands	94	372.15	8	900.77
Andhra Pradesh	21	11832.54	4	372.23
Arunachal Pradesh	9	6177.45	2	2468.23
Assam	8	990.58	2	930.00
Bihar	19	3881.75	2	567.32
Goa	4	355.78	1	107.00
Gujarat	21	16970.16	4	479.67
Haryana	10	342.65	1	1.43
Himachal Pradesh	30	4702.87	2	1295.00
Jammu & Kashmir	15	10157.67	4	3900.07
Karnataka	20	4238.21	5	2471.98
Kerala	12	2143.36	3	536.52
Madhya Pradesh	32	10567.05	11	6485.72
Maharashtra	25	13995.49	5	958.45
Manipur	1	184.85	2	81.00
Meghalaya	3	34.21	2	267.48
Mizoram	3	560.00	2	250.00
Nagaland	3	24.41	1	202.02
Orissa	18	6214.96	2	1212.70
Punjab	6	294.82	0	0
Rajasthan	22	5662.87	4	3856.53
Sikkim	4	92.1	1	850.00
Tamil Nadu	17	2671.03	1	401.63
Tripura	4	603.62		0 0
Uttar Pradesh	29	8107.52	7	5429.83
West Bengal	15	1055.55	5	1692.65
Daman & Diu	1	2.18	-	-
Delhi	1	13.20	-	-
Chandigarh	1	25.42	-	-
Dadra and Nagar Haveli	-	-	-	-
Lakshadweep Islands	-	-	-	-
Pondicherry	-	-	-	-
Total	448	112,274.45	85	35,919.03



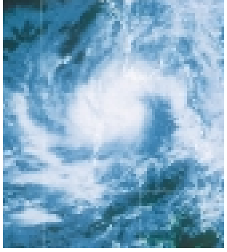
Photo: NMNH, New Delhi

A diorama of Chipko movement at the National Museum of Natural History, New Delhi.

to time. The quarterly journal, *Paryavaran Abstract*, is devoted to the reporting of information on environmental research in the Indian context. A website, Sustainable Development Networking Programme (SDNP), has been developed as a joint project of UNDP and IDRC of Canada and is being implemented by ENVIS.

International Cooperation: The Ministry has been the nodal agency in the country for the United Nations Environment Programme (UNEP); International Centre for Integrated Mountain Development and looks after the follow-up of the United Nations Conference on Environment and Development (UNCED). India is also affirming its concern for environmental protection worldwide and has signed important international agreements, some of which are:

- United Nations Framework Convention on Climate Change;
- Vienna Convention for the Protection of the Ozone Layer (including the Montreal Protocol on Substances that Deplete the Ozone Layer);
- Ramsar Convention on Wetlands;
- Convention on International Trade in Endangered Species (CITES) of flora and fauna;
- United Nations Convention to Combat Desertification;
- Convention on Biological Diversity;
- Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal.



CHAPTER XXXIV

MINISTRY OF NON-CONVENTIONAL ENERGY SOURCES

India is endowed with abundant sunlight, wind, water and biomass as sources of renewable energy. Over the last two decades, vigorous efforts have been made to tap these renewable resources to utilize them for a variety of end use applications such as cooking, drying, heating water, pumping water, lighting and power generation for meeting the decentralized energy requirements in villages, urban areas, schools and hospitals.

In cognizance of the vast potential of renewable energy sources in the country, Government of India set-up a Commission for Additional Sources of Energy (CASE) in 1981 in the Department of Science and Technology which was converted into a separate department i.e. Department of Non-Conventional Energy Sources (DNES) in 1982. A decade later the DNES was upgraded to the Ministry of Non-Conventional Energy Sources (MNES), reflecting the Government's resolve to give a thrust to the renewable energy movement in the country. Three centres of excellence -- Solar Energy Centre, Centre for Wind Energy Technology and National Institute of Renewable Energy -- have also been established for catering to the R & D and Training requirements in the field of renewable energy. The MNES has nine Regional Offices located at Ahmedabad, Bhopal, Bhubaneshwar, Chandigarh, Guwahati, Hyderabad, Patna, Lucknow and Chennai, which carry out monitoring and inspection of projects and maintain liaison with the concerned State Governments and local organizations.

The Government has been implementing one of the world's largest programmes on renewable sources of energy, covering a vide spectrum of renewable energy technologies. Since its inception MNES has been promoting and developing various renewable energy technologies which include improved cooking stoves, biogas plants, biomass gasifiers, solar thermal and solar photovoltaic systems, wind farms, wind mills, biomass based cogeneration, small and micro hydel systems, energy recovery from urban and industrial wastes, hydrogen energy, ocean energy, fuel cell electra vans and gasohol. MNES provides various fiscal and financial incentives to attract private sector participation in implementation of various programmes. Keeping in view the significant potential for generation of power from renewable energy sources, emphasis has been laid upon the generation of grid quality power from renewable.

The country has gained ample field experience in development and utilization of various renewable energy systems/ devises applicable in hard field conditions prevailing in rural as well as urban areas. Technical guidance and help is now also being provided to several other developing countries for the construction of biogass plants, solar photo voltaic (SPV) systems, wind turbines and its components.

Recent Achievements

Using the 'seeing is believing' principle, the Ministry has demonstrated the utilization of renewable energy systems/devices and made them a reality in the daily life of many rural/urban areas, and developed confidence among various users. Some of the major achievements of the Ministry during the last two decades are given below.

- Complete indigenous systems/devices such as biogas plants, improved wood stoves, wind pumps, biomass gasifiers, solar cookers, and solar water heating systems have been developed and vigorously tested under field conditions.
- About 3.2 million family size biogas plants, 3400 community/institutional biogas plants, 33.4 million improved cook wood stoves, 40 MV equivalent biomass gasifier systems for electrical, mechanical and thermal applications, 5 lakh solar cookers, over 5.5 lakhs solar photovoltaic systems including water pumps, 5.5 lakhs square metre collector area equivalent solar water heating systems have been put to use in rural and urban areas.
- Considerable progress has been made in harnessing the large wind power potential available in the country. India now has the fifth largest installed wind power capacity in the world which has reached 1340 MW. About 70-75 per cent indigenization has been attained in Wind Energy Technology.
- Grid quality power generation from renewable sources has attained maturity in India. The total installed capacity has reached about 3041 MW with wind power (1340 MW), biomass power (292 MW), SPV power (1.6 MW), biomass gasifier (37.4 MW), small hydro power (1353.8 MW) and energy from waste (16.2 MW) which is about 3 per cent of the total installed generating capacity of 1.00 lakh MW as per provisional figures of Central Electricity Authority of March 2001.

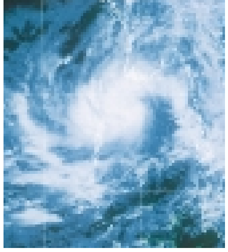
Single crystal silicon solar cells, modules and PV systems have been indigenously developed. A substantial manufacturing infrastructure and consultancy service has also emerged in the country for the design, manufacture and supply of non-conventional energy equipments. These include small scale and medium/large scale industries, both in the public sector as well as the private sector. India is now also in a position to offer its goods, technical expertise and services in this sector, particulary to other developing countries, where similar resource conditions and requirements prevail, particularly solar photovoltaic systems, selectively coated sheets for thermal applications, solar cookers and biomass gasifiers.

Future Plans and Strategy

It is intended to have an exclusive renewable energy policy for the country to provide a fillip to the renewable energy sector. A draft policy has been submitted to the Cabinet for approval. The Ministry has set the following goals to be achieved by the year 2012.

- Electrification of 18,000 remote villages
- Addition of about 10,000 MW of power from renewables
- Setting up of 3 million family size biogas plants
- Improved cook stoves in 30 million households
- Deployment of 5 million solar lanterns and 2 million solar home lighting systems
- Solar water heating systems in one million homes.

The main emphasis is to be laid on the private sector's participation and investments in the over-all development of the renewable energy sector in India.



CHAPTER XXXV

Department of Ocean Development

India is endowed with a well-established maritime tradition. Long coastline and the adventurous nature of our ancestors took us to far off places. As far as ocean sciences are concerned, early nineteen eighties mark the beginning of a new era. The adoption of the Convention of the UN Conference on the Law of the Seas in 1982 established a new international order for the oceans. This extended the economic jurisdiction of coastal states to an area ranging from 200 to 350 miles from the coastline. According to this regime, nearly 2.02 million square kilometres of area, or nearly two-third of the land mass came under India's jurisdiction. In this area, the exclusive right to utilize living and non-living resources vests with the nation.

> FROM MARCH 1982, THE DOD HAS BEEN FUNCTIONING AS A SEPARATE NODAL DEPARTMENT IN LINE WITH THE OCEAN POLICY STATEMENT OF 1982.

The Department of Ocean Development (DOD) was created in Jul, 1981. In 1982, the Government of India issued the Ocean Policy Statement in which control, management and utilization of the internal resources available in the sea and development of appropriate technologies to harness these resources have been emphasized. From March 1982, the DOD has been functioning as a separate nodal department in line with the Ocean Policy Statement of 1982. The programmes pursued by the Department over the years have also kept pace with developments world over and addressed national needs and issues.

In addition to basic knowledge to determine the potentialities inherent in the Indian sea-space we had to develop appropriate technologies to harness these resources. A supporting infrastructure had to be built. Effective systems of management and control of the entire set-up were also necessary. Keeping this in view, various institutional mechanisms were set up, viz. National Institute of Ocean Technology (NIOT) at Chennai, National Centre for Antarctic and Ocean Research (NCAOR) at Goa, and Indian National Centre for Ocean Information Service at Hyderabad. Additionally, the existing institutes and science departments have significantly contributed to DOD's endeavour. A special mention must be made of the National Institute of Oceanography (NIO), Goa, one of the CSIR institutes which has very significantly added information on several disciplines.

The Department's programmes can be broadly classified in the following groups.

- Multi-institutional and multi-disciplinary Polar

Science Programme and Antarctic Expeditions with scientific and geopolitical significance;

- Marine Non-Living Resources Programme – Minerals and Energy;
- Marine Living Resources Programme;
- Marine Environment and Coastal Zone;
- Ocean Atmosphere and Climatology;
- Capacity Building Programme Towards Self-Reliance and Creation of Public Awareness of Ocean, its Potential and Usage.

The scientific research and technology development programmes mentioned above are formulated, coordinated and executed through autonomous institutions attached offices supported by the Department . These multi-disciplinary and multi-institutional programmes are also assisted by national research laboratories, academic institutions and industries. The Department is the nodal agency for international programmes in the ocean sector and represents the country in Inter-Governmental Oceanographic Commission (IOC) of UNESCO, Regional Committee of IOC in Coastal Indian Ocean (IOCINDIO), International Sea-Bed Authority (ISBA) and the State Parties of the United Nations Convention on the Law of the Seas (UNCLOS), the Antarctic Treaty System (ATS) and its scientific and managerial organs – Commission on Conservation of Antarctic Marine Living Resources (CCAMLR), Council of Managers of National Antarctic Programme (COMNAP), andScientific Committee on Antarctic Research (SCAR). These activities have scientific, economic and geopolitical impacts. Further, marine research and capacity building is one of the key areas of the Department to promote basic research in marine science and establish centres of excellence in academic institutions.

SIGNIFICANT ACHIEVEMENTS

During the last two decades the Department has made significant additions to our knowledge of Ocean Science and Technology. Some of these are given below.

Antarctic Programme: Realizing the scientific importance of Antarctica, in addition to strategic, geopolitic, and economic significance in terms of conservation, management and exploitation of living resources in the southern ocean and long-term conservation and management of mineral resources, India entered into the realm of polar science in 1981 with the launch of the first scientific expedition. Since then, India has achieved maturity in launching the expeditions and conducting front rank polar research in various disciplines. The first Indian permanent station *Dakshin Gangotri* was

Top: Work being carried out in Antarctica during summer months in field camps.
Bottom: India's permanent base station Maitri, in SCHIRMARCHER OASIS.







Development of Current Meter Mooring on the equator at 93° east from ORV Sagar Kanya.

established in 1983. Through demonstration of sustained interest and capabilities in polar science and its logistics, India was admitted to the Antarctic Treaty System in 1983 and granted a consultative status in the same year. Later, India established an indigenously built modern station *Maitri* in 1988-89.

So far India has successfully launched twenty multi-disciplinary and multi-institutional expeditions to Antarctica. During the 19th expedition, Dr. (Mrs.) Kanwal Vilku became the first Indian woman to spend 15 months in the icy continent. Besides the annual expeditions to Antarctica, one expedition to the Weddell Sea and one for krill exploration in the Antarctic waters have also been sent. Through these expeditions, a carefully balanced and contemporary scientific research programme has been pursued in the frontier domains of polar science. So far more than 45 national institutions have participated as scientific and logistic components of the expedition thereby putting about 1300 Indians to the icy continent. Among the major contributions in Antarctic sciences are, setting up of a three Component Seismic Observatory at India's permanent Station *Maitri*. This seismic observatory is mainly helpful in monitoring the earthquake activity in Antarctica. A few excellent records of breaking of the ice shelf have been also made by this observatory. A state of art DGPs has been also set up in Antarctica which is helpful in estimating the rate of movement of the Indian plate with respect to the Antarctic plate. The sediments of *Priyadarshini* Lake have been estimated to date back to 10,000 years. Very detailed meteorological and upper atmospheric studies have been undertaken in Antarctica which constitute the necessary baseline to provide inputs to forecast and predict Indian monsoons and weather. On the medical side, detailed investigations carried out on human physiology and psychology under extreme cold conditions have been useful. Valuable experience has been also gained in waste disposal in extreme cold conditions. This knowledge would be helpful in waste disposal at very high mountain terrains of our country. It may be mentioned that by conducting multi-disciplinary scientific experiments and observations in Antarctica, India is making the necessary basis for detailed future investigations. This has also helped the nation to play an active, authoritative and influential role in the affairs of Antarctica through the Antarctic Treaty System and its associated bodies mentioned earlier.

INDIA ENTERED INTO THE REALM OF POLAR SCIENCE IN 1981 WITH THE LAUNCH OF THE FIRST SCIENTIFIC EXPEDITION.

To catalyse and consolidate the gains achieved through the expeditions launched so far and in order to effectively comply with the various international obligations arising out of our consultative status in the Antarctic Treaty, the DOD established a dedicated polar research institute, namely, the NCAOR at Goa.


OTEC barge Sagar Shakti constructed by NIOT with all installations for IMW OTEC power generation.

National Data Buoy Programme: Collection of time series observations of oceanographic and surface meteorological parameters over Indian seas are necessary to improve oceanographic services and predictive capability of short-term and long -term weather/climatic changes as well as to improve the understanding of ocean dynamics. Keeping this in view the National Data Buoy Programme was started in 1997. This forms an important component of the programme on Ocean Observation and Information Services. Till date twelve buoys have been deployed in Indian waters in the depth range of 20 to 4,500 metres.

These data buoys carry sensors to measure wind speed, wind direction, air pressure, air temperature, conductivity, sea surface temperature, current speed, current direction, and wave parameters. The buoys are equipped with global positioning system, beacon lights and satellite transceivers. A few buoys are provided with additional sensors to measure parameters, like radioactivity, light attenuation in three wavelengths, chlorophyll- A and dissolved oxygen. Power to the buoys is provided by solar panels and chargeable battery packs.

A few applications of this programme are:

- *Environment Impact Assessment:* The data collected from the buoys is useful for continuous monitoring of coastal and marine environment.
- *Meteorology:* The real time surface meteorological data obtained by these buoys are vital for a reliable operational weather forecasting model and to alert the coastal population about imminent natural disasters such as depressions and cyclones.
- *Oceanography:* The long term oceanographic data collected from the buoys are useful in enhancing our knowledge of Indian ocean circulation.
- *Fisheries:* The sea surface temperature and water quality parameters obtained from the buoys have been found useful in identifying potential fishing zones.
- *Validation of Satellite Data:* The satellite data can be easily validated with the help of *in-situ* data collected from the boys.
- *Offshore Installations, Ports and Coastal Structures:* The data provided by buoys on waves, wind and current are useful in designing various coastal and offshore structures.
- *Shipping:* The data on sea state, particularly wind, wave and currents, is very useful for navigation.

The data from the buoys is transmitted through two-way INMARSAT-C communication system to



A view of components of OTEC plant assembled on board Sagar Shakthi.

the shore station. Daily data are being disseminated to various user agencies like Indian Meteorological Department, Coast Guard and Navy and various R&D organizations including NIO, Space Applications Centre and Centre for Atmospheric and Oceanic Sciences to meet their specific requirements.

Ocean Thermal Energy Conversion: In tropical oceans, within about 25 degrees north and south latitudes, a temperature difference of about 20° C exists between the waters at the surface of the ocean and at a depth of 1,000 m or so. The process of harnessing the energy due to this temperature difference is called Ocean Thermal Energy Conversion (OTEC). OTEC is an untapped, non-polluting, renewable energy source, which is appropriate for an energy starved nation like India. This method is capital intensive but the unit cost comes down drastically with higher rating plants and improvement in technology.

NIOT, Chennai, is in the process of commissioning a 1 MW OTEC plant off Tuticorin. The plant would generate electricity using the Rankine cycle with ammonia as the working fluid. Design, manufacture and assembly of almost all the components has been completed. The OTEC plant consists of special titanium plate heat exchangers (largest of this kind ever manufactured in the world), special four stage axial ammonia turbine of 1 MW rating, cold seawater and warm water pumps and necessary control and instrumentation. The OTEC plant barge which was constructed at the Dempo Shipyard, Goa is 69 m long, 16 m wide and 4 m high, approximately weighing 500 tonnes and houses all the components of the OTEC plant mentioned above. This plant barge has been named *Sagar Shakthi*. The 1,000 m long, 1 m dia HDPE pipe which will bring cold sea water of 7° C to the plant barge is already assembled and deployed at the OTEC site, approximately 60 km south east of Tuticorin harbour, and upended on reaching the site. It will be integrated with OTEC plant barge, when it reaches the OTEC site.

There are many technology firsts for this plant, like large plate heat exchangers, deep single-point mooring with intake pipe acting as the mooring, large retractable sump for cold water and a specially designed 1 MW ammonia turbine.

This technology demonstration project of 1 MW rating would be the first of its kind in the world and based on the results of the plant, larger plants with 25 MW capacity and above could be built to provide pollution-free renewable energy at a cost compared to other fossil fuelled plants.



Red algae having anti-fungal properties.

Development of Potential Drugs from Ocean: India is endowed with a rich marine biota all along its 8,000 km coastline. The coral reefs that occur in her tropical water demonstrate the highest level of known diversity among marine species. The marine diversity is largely unexplored and, therefore, offers a great challenge and opportunity for new discoveries. A national project on 'Drugs from Sea' was taken up by DOD during 1990-91. This project is being implemented by involving ten institutions with the Central Drug Research Institute (CDRI), Lucknow, as the nodal agency for implementation.

Over 800 different species of marine flora and fauna collected from Indian coasts including island groups were subjected to investigations to identify bioactive compounds. During the last few years, about 4,000 samples were extracted/fractionated and subjected to a wide spectrum of screening for biological activities such as antidiabetic, anti-hyperlipidaemic, antidiarrhoeal, antimicrobial/antiviral, antimalarial, and so on. 597 samples exhibited various types of biological activities and out of these 16 samples were identified for follow up studies in different areas.

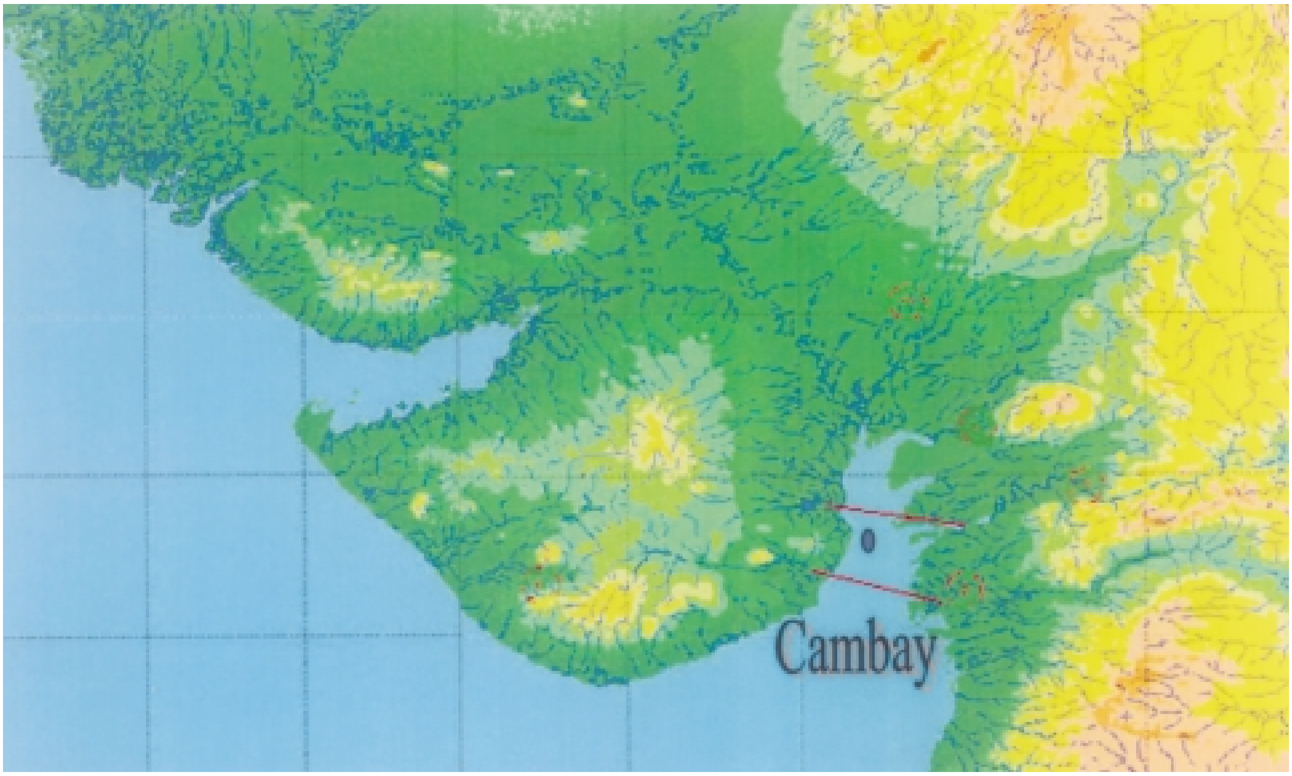
The following organisms mentioned in code numbers have been taken up for product development.

1.	CDR	Antidiabetic/Antidiarrhoeal
2.	CU1/002/004	Antihyperlipidaemic
3.	NIO - 450	Antianxiety
4.	AU-2-106	Antioxidant/ Antihyperlipidaemic/ Antihyperglycaemic
5.	CBM-089	Antibacterial/Antifungal/ Larvicidal
6.	11C - 276	Larvicidal

Over the years, 319 pure compounds have also been isolated. Some of these possessed interesting biological activities while some others, though inactive, had novel chemical structures, like alkaloids, glycosides, aminoacids; fatty alcohol esters and so on. Ocean organisms have been widely used in the *Ayurvedic* system of medicine. The DOD is trying to use these organisms and the results available till date are encouraging.

Polymetallic Nodules Programme: In August 1987, India became the first country in the world to be allotted 150,000 sq. km. of area in the central Indian Ocean for exploration and exploitation of polymetallic nodules under certain obligations and was given the status of a Pioneer Investor under the law of the Sea Convention. This status given was based on the pioneering work of exploration done by India in the central Indian Ocean with the help of exploration technologies developed at the NIO, Goa. As a part of the obligation, India has to relinquish 50% of the allotted area in phases. India has already relinquished 30% of the allotted area to the International Seabed Authority. The balance 20% of the area is proposed to be surrendered by 2001-02.

DOD is currently establishing a 500 kg/ day processing plant to treat ocean nodules. The plant is mainly based on the process developed by the Regional Research Laboratory, Bhubaneswar, and Bhabha Atomic Research Centre, Mumbai. While the plant is being erected, the research activities are continuing to improve process parameters, and to establish the use of secondaries and byproducts



Location of new marine archeological sites discovered earlier this year by NIOT in Cambay shown by blue dot; red lines show the possible sunken river courses.

generated by the process. The plant is expected to be commissioned by the end of 2001.

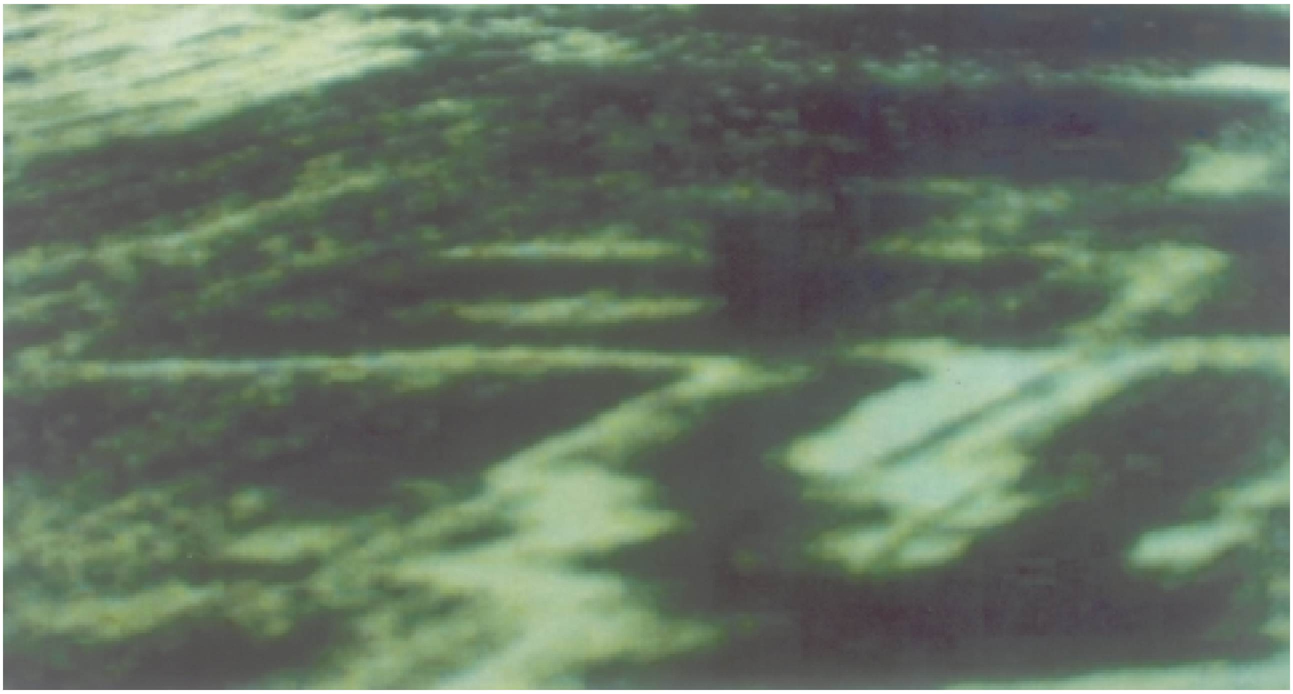
Discovery of a Major Marine Archeology Site in the Gulf of Cambay

The NIOT, has been carrying out multi-disciplinary marine surveys in various parts of the country deploying state-of-the-art sophisticated underwater equipment.

During a recent survey in the Gulf of Cambay, a stretch of formations typical of the riverine regime in the middle of the sea was noted. The materials collected at site included well rounded pebbles, cobbles and alluvium. The Side Scan Sonar has picked images of several excellent geometric objects which are normally manmade. Further research revealed that for almost a stretch 9 km west of Hazira in Gujarat, the area is lined with very well laid house basement-like features, partially covered by the sand waves and sand ripples at depths of 30 to 40 m. The dwellings approximately measure 6 x 8 m^2 to 12 x 16 m^2. The basements are well laid in straight lines with a well-laid drainage system.

The acoustic images obtained point out to the existence of Harappan-like ruins below the seabed. Characterized by tanks 40 x 40 m^2 with steps and acropolis 45 x 20 m^2 like (100 m x 30 m^2) structure of the Harappan culture civilization. These archeological findings have been corroborated by sub-bottom profiler findings wherein the basement reliefs of the foundations have been clearly brought out.

A detailed examination of the geology and tectonics of the area has revealed that a couple of major rivers have been flowing approximately in the east-west direction, coinciding with the course of the present day Tapti and Narmada rivers. Due to geological processes and tectonic events, the entire Cambay area might have sunk taking down with it the then existing part of the river sections and the metropolis.

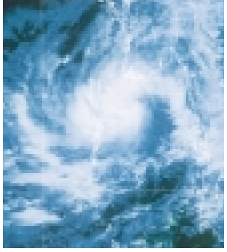


Side-scan images of ruins discovered in the Gulf of Cambay. The estimated size is 40 m x 25 m

NIOT is planning to revisit the site after the present monsoon is over with additional survey equipment for underwater videography and possible sampling. NIOT is coordinating with the NIO, Goa and the Archeological Survey of India in this work.

Concluding Remarks

In this short article, a brief outline of the Department of Ocean Development and a few of its salient achievements have been provided. In the 21st century, Indians will have to depend a lot on sustainable use of ocean resources. Thirty per cent of our population lives in coastal areas. For a better India, we have to make a judicious use of our vast ocean wealth. For this to happen, we have to learn more about our oceans. We have to devise ways to collect meteorological parameters in real time. We need to map and estimate the utilizable potential of our living and non-living resources. The DOD is in the process of developing a vision document for the next 20 years as well as establishing an Ocean Commission on lines with the Space Commission and the Atomic Energy Commission for enhancing our ocean related activities.



CHAPTER XXXVI

ELECTRONICS AND INFORMATION TECHNOLOGY

The Government of India visualized the importance of electronics and information technology (IT) and its critical role in the economic growth of the country, and as a result, established the Department of Electronics (DOE) in June, 1970 and the Electronics Commission in February, 1991. The objectives of the Department were to review the field of electronics with regards to research, development and industrial operations, to formulate policy in the field of electronics and IT and to direct implementation of all measures, both promotional and regulatory, to attain self-reliance. In 1975, the Government of India strategically decided to take effective steps for the development of information systems and utilization of information resources, and also for introducing computer-based decision support system in government ministries and departments to facilitate planning and programme implementation to further the growth of economic and social development (Informatics-led development). In view of its relevance for all round socio-economic growth, and also to get benefit of the emerging digital economy, the Central Government has created a new Ministry of Information Technology (MIT) in 1999 by merging the DOE, National Informatics Centre (NIC) and Electronics and Software Export Promotion Council.

The 1970s saw the Policies of "self-reliance" and "promotion" of an indigenous IT industry in India. The idea that "import of technology could accelerate national development in the field of electronics and computer", had gained support in the Policies/Statements of the Central Government announced between 1978-1984. Many State/Central Electronics Corporations (i.e. KELTRON, MELTRON, UPTRON, WEBEL, HARTRON, ESPL, KEONICS, ELCOT, BEL, ECIL) were established in 1970s and 1980s to develop electronics industry in the states. Various policy announcements like the Import Policy (1983), Computer Policy (1984), Electronic Policy (1985), and Software Policy (1986) laid the foundations for the liberalized growth of IT industry in the country. It was recognized that IT would become strategically as important to the Indian economy as oil.

EMERGING DIGITAL ECONOMY

The global market for IT enabling services is estimated at US $ 585 billion by 2004, of which 5%, or about US $30 billion, could go to Indian companies, (Goldman Sachs Global Equity Research Report). Indian IT sector has recorded a compound annual growth rate of 55% from USD 270 million in 1992 to 5.7 billion in the Fiscal Year 1999-2000. The NASSCOM-McKinsey report projects about USD 87 billion in 2008 for Indian IT Companies. More than 40 per cent of the Fortune 500 companies use the services of Indian enablers. NASSCOM reports that spurred by IT spending by the various State

Governments, Indian software and hardware market (including Devanagari) is slated to touch USD 2.2 billion by 2001.

In the era of globalization and knowledge economy propelled by the phenomenal growth in IT, a paradigm shift in productivity and economic development and in management thought is clearly discernible. Significant growth has been witnessed in the Electronics and IT sector during 1980s and 1990s. The electronics production, in value terms, has increased from Rs. 9,100 millions in 1989-90 to Rs. 6,87,000 millions in 2000-01. The software exports grew from Rs. 1,650 million to Rs. 2,85,000 in 1990s. The outsourced or trans-border IT Enabled Services (ITES) have a great potential for growth and contribution towards employment opportunities in India. Unlike most developing countries, India is expected to gain from the 'emerging Digital Economy', as it has:

- Affordable access to core information resources, cutting edge technology and sophisticated telecommunication systems and infrastructure;
- The capacity to build, operate, manage, and service the technologies involved;
- Policies that promote equitable public participation in the information society as both producers and consumers of information and knowledge; and
- A workforce trained to develop, maintain and provide the value-added products and services required by the information economy.

Information Technology Act (2000) and Communication Convergence Bill (2001) of the Government clearly show the direction in which the country is moving to facilitate a single communication network catering to all types of technologies (i.e. Internet, Datacom, Telecom, Wireless, Wireline, Fixed, Mobile, Cellular, Satellite Communication, etc.), and e-commerce. Public Investment for creation of basic informatics infrastructure with universal access and the consequent creation of employment, has been recommended to be realized by allowing every Central, Centrally sponsored and State Plan projects to utilize up to 3% of their total budget for IT. A National Information Infrastructure (NII) is evolving as a "network of networks" including such nationwide networks as NICNET, ERNET, HVNet & I-Net, in addition to an extensive Fibre Optic Telecommunication Backbone being set up by Department of Telecommunication (DOT), Railways, and the Private Sector.

IT investment in Government Sector has been negligible up to 1990s. The Vittal Committee (1997) constituted by the Department of Administrative Reforms recommended 2-3% of the budget outlay for IT applications in Government Departments. The National Conference on Informatics for Sustainable Agricultural Development (ISDA) 1995 recommended 3-6% of IT applications in the agricultural sector. In the present "crucial decade" of this millennium, a high rate of investment in IT capital and a supportive environment are expected to achieve "digital economy".

National Task Force on Information Technology and Software Development (1998) of the Central Government has suggested a plan of action to make India an IT super power in the World. Emergence of IT on the National Agenda and announcement of IT Policies by about 19 State Governments have strengthened India's position in the software-driven IT sector in the world. These IT policies, more or less, envision: Re-engineering administrative processes, IT Budget, IT initiative fund, Statewide Area Network, Smart Cards, Department-wise specific MIS, IT literacy, and Promotion of IT industry. Many State Governments have introduced "computer education" as a compulsory subject in schools and established Indian Institutes of Information Technology (IIITs), IT Parks, Hardware Parks, and Software Technology Parks to promote the growth of IT education, services, and industry in India. Impact of IT would be predominant in the social sectors like health, education, judiciary and rural development.

Initiatives of the Ministry of Information Technology

The MIT has taken steps to implement a comprehensive action plan to make India an IT Super Power and achieve a target of USD50 billion in software exports by 2008, and to accelerate the internet revolution emphasizing the creation of useful contents in Indian languages. Development of IT enabled services, IT education, electronics and computer hardware manufacturing and exports, silicon facility, e-commerce and Internet based enterprises has become the thrust area of the Ministry. R&D in emerging technological area has remained a key activity of the Ministry and the promotional efforts in electronics and IT have helped enormously in the laying of solid foundation in the IT industry. The Ministry has set up several autonomous organizations, as given below, to address the requirements of different sectors of IT in a focussed manner: Centre for Development of Telematics (C-DOT); National Informatics Centre (NIC); Centre for Development of Advanced Computing (C-DAC); Computer Maintenance Corporation Ltd.; Standardization, Testing & Quality Certifications (STQC) Directorate; Controller of Certification Authority(CCA); National Centre for Software Technology (NCST); Society for Applied Microwave Electronics Engineering and Research (SAMEER); ERNET Society; DOEACC Society; Centre for e-Governance; Centre for Electronics Design and Technology of India (CEDTI); Semiconductor Complex of India (SCI); Electronics Research & Development Centre of India; ET&T; Electronics and Software Export Promotion Council; Technology Development Council; National Radar Council; National Photonics Council; Electronics Materials Development Council.

These organizations are playing a major role in training and development of humanpower for electronics and computer industry. In addition they help and guide the electronics industry by providing infrastructure, policy support, design, consultancy, training, testing, accreditation, market support, and are also actively involved in R&D activities in their specific areas. The Ministry supports and funds technology development through councils set up in various fields. A major result in sponsored research has been the enhancement of technological base and capabilities in the country, besides generating specific products and equipment. Major areas where significant success has been achieved, at par with the developments internationally, through sponsored R&D projects, are as follows:

- Appropriate Automation Programme – Retrofit Automation, Energy Management, Process Controls, Robotics Welding System, & Simulators for Proactive Shop Floor controls;
- Automatic Data Handling Systems for Plan ADGES;
- Axle Counter and Chopper Control Equipment and Interlocking System for Indian Railways;
- Communication, Broadcast & Telemetry – Digital Mobile Radio, Subtitling in regional languages, Spread Spectrum Radio Modem, and UHF Wireless Data Modem;
- 'PARAM' series of Super Computers based on distributive memory architecture;
- Meteorological instruments (i.e. Cyclone Warning Radar, Radiosonde, MST Radar);
- Pollution free vehicles;
- Telemedicine Networks;
- Electronics Industry Development Project (Manpower Component) – Project IMPACT;
- Fibre Optics Application Programme (FOSAPP);
- Future Air Navigation Systems (FANS) programme in Airport navigation;
- HVDC project jointly with BHEL, AP Transco and CPRI;
- Instrumentation for Paper & Pulp, Textiles, Tea, Sugar, Jute Industry;
- Microprocessor Application Programme;
- Microwave Tubes for providing strategic solutions;
- Software for Indian Languages;
- Technologies for Internet, e-Commerce, and

e-Governance; and

- Vehicle Tracking System based on GPS technology.

The Ministry has initiated about 300 R&D projects at more than 100 institutes including industries, academic institutes and research laboratories. Recently emphasis has shifted toward Information & Communication Technologies (ICT) Area for sponsored projects development. Some of the major areas of activities are:

Technologies for Internet, e-Commerce and e-Governance: Netmaster, a software system for traffic monitoring and bandwidth management of the Internet access link has been developed. *Anglabharti*, a rule based machine translation system for translating documents from English to Hindi has been developed. A number of e-governance and e-commerce projects have been undertaken. VOICE, a versatile online information system to address the needs of citizens, civic administration and municipal corporation has been successfully implemented. Another project, knowledge management system KMAP has been developed to help people in an organization to have access to context specific information to help them in decision making process. Tourism Information system is under development in collaboration with Government of Andhra Pradesh. Products for e-commerce applications i.e Internet based credit card and e- cheque alongwith digital certification.

Communication, Broadcast & Telemetry: Digital mobile radio to provide secure and reliable mobile communications with full duplex voice or data with an option for encryption has been prototyped. A stereo console for broadcasting and hardware and software for news room automation has been developed. A system for use in subtitling of feature film telecast in regional languages has been designed and developed. A spread spectrum radio modem has been developed indigenously for various networking applications. UHF wireless data modems for high speed data communications have been designed and developed.

Software for Indian Languages: *Rupanthar*, software developed by NCST was used for transliterating documents in large numbers from English to Hindi and have been used by many organizations like universities for translating names from English to Hindi. E-mail in *Devanagari* and other languages has also been made available in public domain. Development efforts on machine aided translation from English to Indian languages have led to the development of *Anglabharati, Matra* and *Mantra*, the machine translation systems; *Anusarak*, the language accessor; *Varthalap*, a multilingual internet relay chat application, e-mail in regional languages with cross translation possibilities etc. Collaboration with microsoft has resulted in incorporating Indian languages at the kernel level in Windows 2000 and further similar localization efforts for Linux have also been initiated. Software for directory building, spell checker and similar software tools for various Indian languages have been developed.

Automation & Process Control: Process control system which is a display and monitor system and can be customized for any environment has been developed. Robotics welding system for hazardous applications has been developed alongwith a seam tracking system. This is for high quality welding especially for pressure vessels, power plants and heat exchangers. An instrument for monitoring paper cross-directional strength and uniformity has been successfully developed. Retrofit automation for pulp, paper, sugar, jute and tea, steel and textile industry has been completed. Dyeing systems with computerised controls for textile industry and computerized energy management system for steel plant have been developed.

Agro - and Rural Applications: Various agro-instruments like fertilizer testing kit, soil and grain moisture indication instruments, soil nutrient measuring instrument, rice polish measurement

system and multichannel choke indicator to optimize seed spacing, using a tractor have been developed. These instruments are simple to operate and can be produced at nominal costs. Also IT tools for watershed development have been developed alongwith irrigation canal control automation. Solar pumps for rural use have been fabricated. Under Microprocessor Application programme, various infrastructural sectors like water treatment, irrigation and road were addressed.

Microelectronics & Photonics: In this area various semiconductor devices have been developed alongwith manufacturing technologies to improve the yield of semiconductor devices. Other important results of R&D efforts in this area are development of Optical fiber, nano technology, need-specific detectors for high-speed optical communications and optical receiver module etc.

Power Electronics: Major initiative of DOE in this area is HVDC project funded jointly with BHEL with AP Transco and CPRI as the main executing agencies. Hardware and software for state-of-the-art Digital Control and Protection System have been indigenously developed. Many subsystems and devices like 200MW thyristor have been developed as a part of this project. Supervisory control and the data acquisition system developed is under use at 1500MW Chandpur Padghe Commercial HVDC project. In addition, lightning protection unit, ATE for UPS also have been designed and developed.

Autonomous Organizations

Centre for Development of Telematics (C-DOT): Development of Telecommunications equipment and technologies have been areas of priority for the DOE. C-DOT was established in 1984 with a mission to develop switching system/exchanges in India to work in harsh tropical environment of the country. C-DOT has developed a wide range of Digital and Rural Switching Systems between 200 lines to 40,000 lines. C-DOT technology based design has now about 17 million lines manufactured by over 20 different cooperatives and has revolutionized rural telecom in India. A number of items of equipment including ISDN and Intelligent Networks have been added. C-DOT was subsequently transferred to the Department of Telecommunications, which is the nodal Ministry for Telecom in India.

National Informatics Centre (NIC): National Informatics Centre (NIC) is a premier S&T organization of the Government of India in the field of Informatics Services and IT applications. NIC was set up in 1977 as a constituent unit under the aegis of DOE to provide computer-based informatics services to Government and other agencies having majority funding by the Government. The nation-wide Computer-Communication Network, NICNET, set up by the NIC, is the Government Network. NIC is offering network services over C-band and Ku-band (TDMA, FTDMA & SCPC) VSATs, Wireless Metropolitan Area Networks (MANs) and Local Area Networks (LANs) with NICNET gateway for Internet resources, to promote economic, social, scientific and technological activities, and also for macro-economic adjustment programme of the Government.

During the last 25 years, NIC has played an important role as an 'active, catalyst and facilitator' in informatics development programmes in Governments at the national, state and district level, which made them take policy decisions to create 'knowledge societies' – societies that can exploit knowledge to derive competitive advantage using the opportunities provided by 'digital technology'. NIC has been instrumental in adopting IT and Communication Technology 'to reach out into India' (i.e. by implementing IT applications in social and public administrations), which are discernible from the following developments:

- Central Government Informatics Development Programme- A strategic decision to overcome 'Digital Divide' in Central Government Departments and Ministries during the Fifth

Plan Period (i.e. 1972-77);

- NICNET gateway for Internet/Intranet Access and Resources Sharing in Central Government agencies in 1980s and 1990s;
- IT in Social Applications and Public Administrations;
- State Government Informatics Development Programme – A strategic decision to overcome 'Digital Divide' in Central and State Governments during the Seventh Plan Period (i.e. 1985-1990);
- NICNET – A first of its kind among the developing countries, using the state-of-the-art Ku-band VSAT technology-facilitates (i) decentralized planning, (ii) improvement in government services, and (iii) wider transparency of national and local governments and improving their accountability to the people;
- DISNIC – A District Government Informatics Programme based on NICNET : A strategic decision in 1985 to overcome 'Digital Divide' in 540 District Administrations;
- Reaching out into India during 1985-90, even before the arrival of 'Internet' Technology, to 540 districts of the country, which is a land of diversity with different types of terrain, various agro-climatic conditions, different levels of socio-economic conditions, and varied levels of regional development, etc.

Some of the important IT projects, undertaken by NIC in the Central and Centrally Sponsored Sector Programmes, are: Budget Computerization; Central Excise Computerization; Commercial Tax Computerization; Community Information centre Project; Corporate Companies Computerization; Courts Computerization Project – Supreme Court, High Courts, and District Courts; Customs computerization, and EDI implementation; District Information system; District Rural Development Agency Computerization project; District Treasury Computerization; e-Governance and e-Commerce Project; Parliamentary Elections data transmission and analysis; Employment Exchange Computerization; National Drinking Water Technology Mission Project Computerization; Passport Computerization; Registration Department Computerization (CARD Project); Road Transport Vehicles Registration Computerization; Utility Mapping Project.

'Indian Image' is a popular Web Site of NIC which presents a true perspective of India and its Government before the Internet Community.

NIC has assisted many government bodies including Parliament to prepare and implement their IT plans. It has signed Memorandum of Understanding (MoU) with State/UT Governments to strengthen decision support in Government departments in 28 State capitals, one NCT and 6 Union Territories and 520 district centres. NICNET facilities are utilized for the development of computer based Government informatics at the state/district level. State Government departments utilize NICNET facilities for on-line monitoring of various sectors of economy and social development on a regular basis and also for database development for administration and planning. Starting as a small programme under an external stimulus by an UNDP project, it has grown incrementally and later exponentially as one of India's major S&T organizations promoting 'Informatics-led Development', which has helped to usher in the required transformation to cope with the trends in the new millennium.

Education and Research Network (ERNET): ERNET was the first major network in India to cater to the requirements of Education and Research community. ERNET has been providing internet services to this community since 1990. Presently ERNET provides connectivity to over 750 organizations representing a mix of universities, R&D laboratories, NGOs and has over 80,000 users. ERNET collaborates with premier institutes in the country to undertake advanced research projects.

CMC Limited: CMC Limited commenced operations as 'Computer Maintenance Corporation'

in the year 1976. CMC took up the challenge to service all computer installations of IBM, when IBM decided to wind up its operations in India in 1978. Later CMC also maintained computers supplied by scores of other foreign manufacturers.

Today, CMC is one of the leading IT companies in the country with multi-faceted expertise. CMC has five strategic business units in the areas of customer services, systems integration, international operation, education and training and Indonet. CMC still enjoys leadership in Third Party Maintenance. CMC continues to consolidate its position in the area of Networking Services alongwith its data centre activities. Keeping in line with the thrust on increasing international component of business in all areas, CMC is working in areas like VLSI design, tool support, network management, system administration etc. CMC has over 3000 employees with 18 offices in India and more than 150 service locations. Some of the important projects undertaken by CMC are:

Railway Reservation and Freight Operation Information System; Finger Print Identification System for India and Mauritius; On-line integrated customer based retail banking system; GENISYS (General Insurance System); India's first Integrated Operating Office Software for New India Assurance Co.Ltd.; Bombay Stock Exchange's On-Line Trading (BOLT), a comprehensive screen based trading software was indigenously developed by CMC; Application Specific Development Centre for SCADA (ASDC-SCADA) at Hyderabad has developed and supported many SCADA applications in electric power transmission and distribution; e-commerce solutions; e-governance solution for Municipal Corporation of Vijayawada and others; Vehicle Tracking System; BRI Inc. is CMC's wholly owned subsidiary in USA. CMC has executed many international projects in areas of networking, data warehousing, web and internet based solution, embedded systems, software testing, computerisation of ports, stock exchanges etc.

Centre for Development of Advanced Computing

The Centre for Development of Advanced Computing (C-DAC) is an autonomous scientific society established by the MIT. It was set up over a decade ago, as India's national initiative for indigenous design, development and delivery of high performance computing (supercomputer systems) and solutions based on parallel processing technology. C-DAC has, over the years, diversified its activities, transferring the expertise it acquired and technologies it developed in the high-end computing, to develop and deploy IT based solutions in various sectors of the economy. Through this approach, it has maintained a balance between developing strategic technologies on the one hand, needed by the country in the high performance computing area for achieving self-reliance and addressing mission-oriented critical problems in the science and engineering fields, and, on the other, using expertise developed to commercialize its technologies and products to meet the requirements in various sectors.

C-DAC has been operating in a mission mode in order to develop the technologies in the specific time-targeted manner. It has accordingly brought out in its earlier missions, the PARAM series of Supercomputers. C-DAC's current mission is for the development of the next generation High Performance Computing & Communications (HPCC) technologies and applications, taking advantage of the developments carried out in its previous missions in this area. As part of this, C-DAC has set up a National PARAM Supercomputing Facility (NPSF) to allow access to researchers to solve their computer intensive problems in various areas of science and engineering.

Language Technology Mission: C-DAC's other activity, the language technology mission, is to create a framework for support to the various living languages with diverse scripts on standard computers. C-DAC has innovated its trail-blazing Graphics and Intelligence-based Script Technology

(GIST) to achieve this goal. This technology is now extended to include multimedia and multilingual computing solutions covering a wide range of applications such as publishing and printing, word processing, office application suites with language interfaces for popular third party softwares on various operating platforms, electronic mail, machine translation, language learning, video and television, and multimedia content in Indian languages. These have been successfully commercialized.

C-DAC has established its Advanced Computing Training School (ACTS). This school currently offers a variety of course options in software technologies, Enterprise System Management (ESM), Geomatics, VLSI designs, digital multimedia etc. at its own four centres and about 100 franchise centres around the country.

Building on its foundation in almost all major areas of IT, C-DAC offers advanced computing products, solutions and services to several sectors including education, research, power, telecom, health care, finance, transport, networking and internet applications. Specific areas of focus currently are e-governance, e-commerce, digital libraries and advanced solutions based on data warehousing, genetic algorithms, network security, GIS, artificial intelligence, real time systems, and so on. Under the Data Warehousing Project for Andhra Pradesh Government, C-DAC developed citizen's database (Voters List, Food and Distribution, Industry, Professionals, Household data, Health, Economic Status and Demographic data).

Software Technology Parks of India (STPI): The export of computer software has received special thrust and has become the largest item being exported in the IT sector. STPI acts as a single window solution provider for organizations engaged in export of IT Software and Services. It provides infrastructural facilities, including High Speed Data Communication Services (HSDC), required by the IT industry and it solicits all the Government approvals as required by this industry.

Eighteen earth stations have been established which act as International Gateways. STPI also provides incubating infrastructure mainly for start-up operations of Small and Medium Entrepreneurs (SMEs) enabling them to commence their operations without any gestation period. STPI has also set up a 'Business Support Centre' in the Silicon Valley (USA) area in order to support the Small and Medium Enterprises (SMEs).

As a result of focused attention to the software exports sector, STP schemes have attracted many entrepreneurs in the area of software development. A total of 6329 units are registered with STPI. The export revenue of the STP units is showing consistent growth of more than 100% every year.

National Centre for Software Technology (NCST): NCST, a premier R&D institution in software technology, has developed its reputation as the National Laboratory for Software Technology. It has retained its R&D character and has expanded into education and training. It has won national and international recognition and is performing valuable role in educating and training high level technologists for Indian business and industry. As a part of the centre for excellence in virtual computing, a multimedia virtual environments laboratory has been created. A world class Virtual Reality (VR) application, created as a walkthrough of the Fatehpur Sikri monument has been demonstrated widely and has been well received around the world. INTEL, which also donated some equipment to its laboratory, has included this application in its demo CD for showing 3D graphics power of its high end processors.

NCST's activities as Domain Registrar for India have increased several-fold, as the Internet revolution has rolled along. Software developed by NCST has been used by many reputed organizations including TCS and INFOSYS within the country. NCST's significant achievement is development of Hindi Version of Windows 2000, which has been released by Microsoft Corporation, USA recently.

Society for Applied Microwave Electronics Engineering and Research (SAMEER): SAMEER, with three Centres at Mumbai, Chennai and Kolkata, is engaged in R&D in areas of microwave engineering and applied electromagnetics. Its thrust areas are microwave and RF applications in industry, instrumentation and health, linear accelerator technology, millimeterwave electromagnetic compatibility and antennas. SAMEER has contributed in development of national facilities like Mesosphere, Stratosphere and Troposphere (MST) Radar at Gadanki, Andhra Pradesh which is being used for atmospheric studies.

Electromagnetic Compatibility (EMC), meteorology and consultancy are the major activities of SAMEER at the Chennai centre. In communication engineering area SAMEER has designed, developed and commissioned dedicated Microwave Data Link System (MDLS) for strategic applications; hardware for CDMA-based digital data link; powerline frequency magnetic field meter; broadband sleeve monopole antenna; whip antenna and printed antenna for Wireless Local Loop System.

Electronics Research & Development Centre of India (ER&DCI): Electronics Research & Development Centre of India (ER&DCI) has mandate to promote and establish modern, state-of-the-art, scientific research and development in electronics and to design and develop electronics equipment and systems for the growth of electronics industry. ER&DCI is operational at three centres at Thiruvananthapuram, Kolkata and Noida. Recognizing the importance of internet, ER&DCI has accorded special emphasis to the development of low-cost Net-PCs, Set-Top box and Internet appliances. Other technological developments include embedded JAVA controllers, System-on-chip products and networking hardware.

Standardization, Testing & Quality Certification (STQC): STQC Directorate is a premier institution in the country dedicated to provide total quality solutions to the Indian Electronics and IT industry by way of establishing a nation-wide quality assurance infrastructure. The STQC Directorate is providing a wide range of the quality related services to the Indian industry through a network of test laboratories located all over the country. Some of its important functions are: Standardization support at the National/ International level; Implementation of National and International level Certification schemes covering aspects of performance, safety, Electromagnetic Compatibility (Radio Interference), Quality and Environment Management Systems as well as Information Security; Testing of electronic products against national/international standards; Calibration of measuring intruments to ensure measurement traceability ; Product/Quality system development support, Counselling and Training; and Reliability Assessment and Failure Analysis.

Human Resource Development

Ever since the setting up of DOE, development of human resources in electronics have always been a prime goal. In early 1980's projects generate talented young persons with M.Tech degree in Microwaves and Underwater Electronics were initiated by DOE at the University of Delhi and IIT, Delhi respectively. Later, in March 1985, while announcing the Integrated Policy measures on electronics, a great deal of emphasis was laid on humanpower development in the electronics sector. As a result, the following programmes were initiated to train a wide spectrum of professionals at all levels in the area of electronics and computers.

(i) Master of Computer Applications (MCA) Programme : This programme was started at various institutions and universities. The entire course structure and the curriculum for this programme was developed and adopted by over 500 institutions.

(ii) DOE/UGC Programme in Electronics : M.Sc in Electronics was started in 11 centres. This Course

was later incorporated in almost all the universities.

(iii) Post-B.Sc. Diploma in Computer Application (PGDCA) : This diploma course was initiated in 28 centres and is now being offered by many institutions.

(iv) Teachers' Training Programme : Five major institutions viz, the four IITs (Mumbai, Delhi, Kanpur and Chennai) and Jadavpur University have established training programmes for teachers in Computer Science. A separate training programme for training faculty for Diploma level courses in computer applications was initiated at six institutions across the country.

(v) DOE, in consultation with Department of Education and UGC, has set up a chain of four Indian Institutes Information Technology (IIITs) in four regions of the country.

(vi) Class Programme: DOE, alongwith CMC, started this programme of computer education in schools.

Electronics Industry Development Project (Manpower Component) Project IMPACT: The project IMPACT (Industry oriented Manpower with Appropriate Competence and Training) was initiated in 1991 jointly by the Swiss Agency for Development and Cooperation (SDC), World Bank and the Government of India with the objective of improving the quality and relevance of education and training in the field of electronics and computers. The project involves 14 engineering colleges and 12 polytechnics. Project IMPACT has made a substantial impact in changing the culture of electronics engineering and computer sciences education at these colleges and has helped the industry through increased availability of better trained personnel in IT. A Sustainability Support Scheme was initiated in January, 1998 to ensure that the benefits of the project IMPACT are sustained at the participating institutions.

Centre for Electronics Design & Technology of India (CEDTI): CEDTI has seven Centres located at Aurangabad, Calicut, Gorakhpur, Imphal, Srinagar/Jammu, Mohali and Tezpur. Some of the long-term courses offered by these centres are Diploma in Electronics Production and Maintenance, M.Tech in Electronic Design Technology and DOEACC "A & B" (see below) level computer courses. Thousands of students including professionals from industry are participating in these courses.

DOEACC Scheme

The DOEACC (Department of Electronics Accreditation of Computer Courses) started in August 1990 with the following objectives:

- to utilize the facilities and infrastructure available in the private institutions to generate quality manpower in the area of computers.
- enhance the quality of computer manpower training imparted by private sector institutions.

Under this scheme, the institutes meeting the defined quality and service standards are given accreditation for conducting specified level of courses 'O' (foundation level), 'A' (advanced diploma), 'B' (graduate level), 'C' (post-graduate level). The curricula for these courses are defined by the DOEACC Society, which also conducts examinations in these courses. So far about 600 institutes have been accredited for conducting various levels of DOEACC courses.

Technology Development in Indian Languages (TDIL): TDIL Programme is a vehicle to carry the IT benefits to the masses of the country and minimize the digital divide. This programme promotes the development of information processing tools to facilitate human-machine interaction in Indian languages and to create and access multi-lingual knowledge resources. It also promotes the use of information processing tools for language studies and research.

The Ministry has also established thirteen Resource Centres for Indian Language Technology Solutions, covering all the languages included under the Indian Constitution.

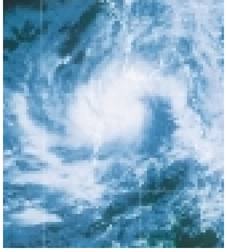
Some Initiatives of MIT

- *Controller of Certifying Authority(CCA) :* As part of IT Act 2000, Office of the CCA has been created to set up and regulate a country-wide infrastructure of certifying authorities to issue digital signatures, which are passport to the cyber world.
- *e-Commerce & Internet Security:* To foster greater synergy among the activities/initiatives in the overlapping areas of e-commerce, an independent division with the title 'IT Act and information security' was created in January, 2001. Besides being a proactive facilitator, this division provides a single point interface to all the concerned agencies.
- *Community Information Centre:* The MIT has taken up an ambitious project for setting up of Community Information Centres (CICs) in 446 blocks in the seven North-Eastern States and 40 blocks in Sikkim as a part of the Prime Minister's agenda for the socio-economic development of the region. The CICs in each block will be provided with a VSAT link, a server and computers with other facilities to ensure comprehensive communication ability at a place. All the blocks will be connected to a close user group network as also internet and in the process connected to District Information Centres and State Information Centres of North East and Sikkim states through Virtual Private Networks or otherwise. The project will be implemented in two years.
- *Centre for e-Governance:* MIT is examining the practical implications of IT-related issues in the Government to provide better services to citizens and improve internal working in the Government. A centre has been set up for this purpose to provide general information on e-governance and also to take care of major policy issues related to e-governance.
- *Course in Cyber-law:* To increase awareness among the judiciary, attorneys, prosecutors and the police a PG Diploma Course on cyber law and Intellectual Property Rights has been inititated. This nine- month PG Diploma course has been sponsored at the Indian Law Institute, New Delhi.



INTERNATIONAL LINKAGES

With extraordinary explosion of knowledge, speedy travel and evolution in information technology, increasing awareness of global concerns, the world community of scientists has felt the need and has realized the value of establishing closer ties by removing barriers. This chapter briefly reports the progress made by India through government departments , autonomous societies and academies in fostering international relationship.



CHAPTER XXXVII

International Linkages

Science and technology (S&T) was accorded the pivotal role in the national development of India on emergence from colonial rule. Along with the material infrastructure that the country began to place on the ground, special attention was paid to the two dynamic aspects that would carry the country forward into the contemporary modern era: the expansion of education and training in scientific and engineering disciplines, on the one hand, and the promotion of research, both in the pure sciences and in S&T as well, so as to give full scope to the aptitudes and talents in Indian culture to attain their best potential. Indian science aimed to make meaningful contribution to and take its rightful place in the world scientific endeavours. Comprehensive structures and processes evolved over the years and these comprised academic institutions, laboratories, R&D organizations along with programmes of collaboration and interaction with other countries and international organizations.

The linkages established by Indian science are based on three major considerations: the scope for fruitful interaction in areas of common interest; opportunity to render assistance through joint activities; and the possibility for participation in newer domains of study and research. From time to time other considerations too are included.

A programme for cooperation in science and technology is adopted after due assessment of its scientific level, the nature of the proposed interaction, the availability of resources, both technical and financial and the relevant administrative aspects. The interactions generally cover such areas as conducting joint experiments, sharing equipment and material, exchange of information, exchange of visits by scientists, holding joint workshops and seminars, training of technical personnel and award of research fellowships.

In addition to these bilateral arrangements, India also has programmes of cooperation with several countries on a regional basis. The Indo-EC relations cover India's cooperation with a number of European nations within the European Economic Community (EEC). With countries like Germany and the Netherlands, India has, thus, a dual relationship, one directly on a bilateral basis and the other as the members of the EC. Under the South

India's Partners in Science

India has arrangements for cooperation with more than 50 countries round the world, ranging from the most scientifically advanced to those yet in transition: Australia, Belarus, Brazil, China, Cuba, Democratic People's Republic of Korea, Egypt, France, Germany, Hungary, Indonesia, Iran, Israel, Italy, Japan, Kazakhstan, Kyrgyzstan, Mauritius, Mongolia, the Netherlands, Pakistan, Poland, the Republic of Korea, Russia, South Africa, Sri Lanka, Sweden, Tajikistan, Turkey, Ukraine, United Kingdom, United States of America, Uzbekistan, and Vietnam.

Asian Association for Regional Cooperation (SAARC) arrangement, India interacts with the other members of SAARC on a regional basis. The third regional arrangement, with the Association of South East Asian Countries, provides India with a forum for interaction with ASEAN members.

Besides these inter-governmental arrangements, India also has well defined channels of interaction with the various UN agencies, such as FAO, UNESCO, UNDP, WHO and WMO. It also participates in the programmes of the international bodies like the Third World Academy of Sciences (TWAS), and the Centre for Non-Aligned and Other Developing Countries. The Department of Science and Technology (DST) is the nodal agency of the Government of India designated to deal with the country's international affairs, in coordination with the other concerned departments and organizations.

Bilateral Cooperation

For the purpose of an overview of India's bilateral dealings with other countries, we shall consider the instances with China, France, Germany, Japan, Mauritius, Russia, USA, and Vietnam. The aim is twofold: to highlight the unique nature of India's interaction with each country, an also to indicate the broad spectrum of activities under the various programmes of cooperation.

China: Initial bilateral contacts in S&T between India and China began with exchange of visits by scientific delegations, which followed the Official Level Talks that were periodically held between the two Governments, to review the status of diplomatic relations between them. Views on possible interaction in S&T were also exchanged at these meetings. Exchange of visits of scientific teams took place in a number of areas, including Seismology and Earthquake Engineering, Chemistry of Natural Products, Laser Technology and Plasma Physics, Astronomy, and Biotechnology, and these continued until 1988.

In December 1988, a formal Agreement on Cooperation in Science and Technology was signed in Beijing and eight priority areas were identified for future cooperation: Lasers; Materials and Earth Sciences; Chemical Engineering; Medicine; Biotechnology; Agriculture and Fisheries; Electronics; and Space and Remote Sensing. Some additional programmes were also identified in the protocols signed between some Indian and Chinese organizations, under the provisions of the S&T Agreement such as, joint workshops in the areas of Aerodynamics and Propulsion and Composite Materials.

France: An inter-governmental agreement on Cultural, Scientific and Technical Cooperation between India and France, signed in June 1966, made a specific provision for facilitating interactions between the scientists of the two countries, in particular those working in their academic institutions. A more comprehensive treaty for strengthening bilateral relations in S&T was concluded twelve years later, in July 1978, in the form of an Agreement for Cooperation in science and technology.

The implementation of this Agreement took place in accordance with the recommendations of a joint committee, consisting of representatives of the two countries, which deliberated on areas of mutual interest, scope and mechanisms of cooperation, and the funding of joint activities. Collaborative programmes were developed in Computer Science, Automation, Aeronautical Engineering, Immunology of Reproduction Control, Oncology, Oil Seeds and Soil Microbiology, and implemented through exchange visits of scientists, participation in training programmes and advanced courses, and joint workshops. In addition, a number of Protocols were signed, which included those in Renewable Energies; Ocean Science and Technology; Medical Research; and Biotechnology. In 1990, a special agreement on cooperation was also concluded between the CSIR and the Centre National de la

Recherche Scientifique (CNRS).

An important advance in bilateral scientific relations was made with the establishment of the Indo-French Centre for the Promotion of Advanced Research (IFCPAR) in New Delhi. Envisaged as a nodal office for *piloting and financing of research programmes carried out jointly by the Indian and French teams*, it was registered as an autonomous society under the jurisdiction of Indian law, and started functioning in 1987, under the purview of the DST of the Government of India and the Ministry of External Relations of the Government of France. Since its inception, IFCPAR has funded over 180 collaborative projects, organized several joint workshops and seminars, and sponsored the preparation of some state-of-the-art reports. The areas of priority interest have been Pure and Applied Mathematics, Computer and Information Sciences, Life and Health Sciences, Pure and Applied Physics, Pure and Applied Chemistry, Instrumentation, Geosciences, Material Sciences, and Environmental Sciences and Water. A large number of joint scientific papers have resulted from these collaborations.


Photo: A.K. Kalra, DST

Professor Murli Manohar Joshi, Hon'ble Minister of Human Resource Development, S&T and Ocean Development and Dr. Jose Mariano Gago, Minister of S&T, Portuguese Republic signing bilateral Programme of Cooperation in S&T in Lisbon, Portugal, on July 3, 2001.

Germany: Historically, when West Germany (Federal Republic of Germany) and East Germany (German Democratic Republic) existed as separate nations, each of them had independent S&T relations with India. Following their unification in October 1990, the diplomatic protocols between India and Germany were revised, and these included a renewed arrangement for cooperation in S&T. The pattern of this cooperation retained the basic features that had evolved after the signing of the Agreement on Cooperation Regarding the Peaceful Uses of Atomic Energy and Space Research and the 1974 Agreement on Cooperation in the Field of Scientific Research and Technological Development signed between India and West Germany.

The Special Agreements for implementing programmes were signed in the fields of Nuclear Research and Development (1974), Space Research and Space Technology (1974), Scientific Research and Technological Development (1974, 1986, 1993), Medicine and Biology (1976), and Aeronautical Science (1982). Collaborative interaction between institutions of the two countries took place in a wide range of areas, resulting in joint studies and research publications.

Though the above inter-governmental agreements were signed only in 1971 and later, other bilateral arrangements had existed since the 1950s providing for the visits of scientists and engineers,in the form of Exchange Programmes between (i) UGC and German Academic Exchange Service (DAAD), (ii) CSIR and DAAD, (iii) UGC and Alexander von

Humboldt Foundation, and (iv) Indian National Science Academy and German Research Foundation. The establishment of the IIT at Chennai, and the building and equipping of the research vessel *Sagar Kanya*, are two notable examples of the Indo-German Technical Cooperation Programme.

Against the backdrop of these wide-ranging linkages between the scientific communities of the two countries, the Indian Prime Minister and the German Chancellor decided in early 1994 that for further promotion of S&T cooperation between India and Germany, a German-India Committee on Science and Technology should be set up. This Committee met for the first time in Bonn during October 1994, when it adopted its mandate and reviewed some of the other issues relevant to the future. Reference should be made to two novel initiatives have emerged from the deliberations of this Committee: the first, improving the availability and diffusion of information on activities within S&T co-operation, and the second, developing measures to promote an enhanced involvement of industry.

> ALL NOBLE THOUGHTS SHOULD COME FROM ALL OVER THE WORLD
>
> *ṚGVEDA*

Japan: The establishment of scientific relations with Japan may be divided into three phases. The first phase commenced with the posting of a Science Attache in the Embassy of India in Tokyo in the mid-seventies, with the aim of keeping abreast with the scientific and technological developments taking place in Japan. The Science Attache was also be in a position to assist Japanese agencies and individuals with information about the S&T scene in India. A symposium on Japan-India Cooperation in S&T took place in Tokyo in April 1975, followed by some exchange visits between the two countries.

The second phase started about a decade later, with the signing of an Agreement on S&T Cooperation in November 1985. However, The level of interaction in the various areas identified for collaboration remained at a low key. In 1992, fillip was provided by a meeting held in Tokyo between the Japan Society for the Promotion of Science (JSPS) and an Indian S&T delegation specially nominated for this purpose. The implementation of the recommendations of this meeting resulted in what could well be regarded as the third and the most active phase of S&T interaction between Japan and India.

Joint projects were implemented in the areas of Molecular Structure, Spectroscopy and Dynamics; New Materials; Modern Biology and Biotechnology; Manufacturing Science; and in Astronomy and Astrophysics. A large number of exchange visits by the scientists have taken place, and several joint workshops have been organized, both in India and Japan. In addition, postdoctoral and predoctoral fellowships have been awarded to a number of Indian scientists. Several other initiatives from both the sides have further contributed to raising the level and scope of interactions.

Mauritius: The range and scope of scientific interaction with this nation of islands off the east coast of Africa has been more limited. It began with a programme on Radio Observations of the Centre of our Galaxy from Mauritius, shared by the Indian Institute of Science, the Raman Research Institute in Bangalore and the University of Mauritius in 1986-87. Supported under the Programme for Technical Cooperation with Developing Countries (TCDC), the project was to establish a Radio-Telescopic Observatory in Mauritius, a country whose geographic location was ideal for making astronomical observations on the Centre of the Galaxy. The Government of India spent over Rs. 15 millions towards the fabrication of equipment, its transportation and installation, training of S&T

personnel from Mauritius in India, and other technical inputs.

The scientific and technical contacts between the two countries developed beyond the scope of the Radio Telescope project and an inter-governmental Agreement was signed in January 1990. It provided for exchange of scientific information, exchange visits of scientists and training of Mauritian scientists in a number of areas, including Agricultural and Horticultural Research, Building Research, Environment, Geology, Health and Medical Science, and Renewable Energy.

Russia: Following the break up of the erstwhile USSR in December 1991, the Government of India embarked on wide-ranging negotiations with the Governments of the Russian Federation and the other newly formed States to establish diplomatic relations with them as independent nations. Exploring possible linkages in science and technology was a part of these negotiations. An Agreement on S&T Cooperation with Russia was signed in June 1994.

The arrangement with Russia was cast into a framework similar to the one that had existed earlier with the Soviet Union, after incorporating the relevant organizsational changes and financial terms. The two main components of this cooperation were (i) the Integrated Long Term Programme of Cooperation (ILTP), and (ii) Other Activities of bilateral interest. ILTP focused attention on thrust areas, such as Biotechnology and Immunology; Materials Science and Technology; Materials and Technology for Electronics; Laser S&T; Catalysis; Space S&T; Accelerators, Water Technology; and Computers and Electronics; and, in the second part, on Basic Research in Mathematics; Theoretical and Applied Mechanics; Earth Sciences; Radiophysics and Astrophysics; Ecology and Environment; Chemical Sciences; and Biology. Besides these, interactions have also taken place in the areas of Agriculture, Standardization and Metrology, Non-conventional Sources of Energy, Building Materials, and Meteorology.

ILTP Fellowships have been awared to eminent Russian scientists in the age group of 35 to 45 years, from the areas of Engineering, Physical and Life Sciences, to work in Indian laboratories for a period of six months to one year. Another initiative was the institution of the SN Bose-MV Lomonosov Lectures in Engineering, Physical and Life Sciences, which are delivered once a year in India and in Russia.

USA: The earliest linkages in S&T between India and the United States date back to the 1950s and 1960s, in the form of interaction between their agricultural scientists, joint projects in health, and establishment of several institutions of learning in India, including a number of agricultural universities in the various states and the IIT at Kanpur. These programmes were supported with the assistance of USAID and grants from PL-480 Rupee funds. Bilateral cooperation was further strengthened by the Exchange Programme between CSIR and National Science Foundation (1967), which provided 800 man-days of visit to each country. Besides the scientists from CSIR laboratories, this programme was also open to senior faculty of Indian universities and the IITs. Exchange of visits took place in the areas of Electronics, Earth Sciences, Instrumentation, Metallurgy, Natural Products, Toxicology and later, Biotechnology. Many of the visits led to formulation of collaborative research proposals, which were submitted for funding from PL-480 rupees. These Exchange Programmes were discontinued in 1991.

The bilateral relations in science and technology were cast into a broader framework when an intergovernmental Agreement (October 1974) decided to constitute an Indo-US Joint Commission, for exploring "the possibilities of fostering mutually advantageous cooperation" in economic, commercial, scientific, technological, educational, and cultural fields. In the fields of science and technology, the Commission was empowered (i) "to review and recommend plans for co-operation between the two countries and

measures for their implementation and co-ordination, which may include *inter alia* the exchange of specialists and information and the organization of bilateral seminars on problems of common interest", and (ii) "to identify common scientific and technological problems and to formulate and recommend joint research programmes which lead to application of results in industry, agriculture, health and other fields."

Following this Agreement, the two Governments constituted the Indo-US Subcommission on Science and Technology, for dealing with S&T cooperation in 1975. The identified areas of interaction were: (a) Health, Medical and Life Sciences; (b) Physical Sciences : Materials, Modern Optics, Electronics, Metrology; (c) Earth Sciences; (d) Atmospheric and Marine Sciences;(e) Environment and Ecology; (f) Energy; and (g) Information Sciences. The implementation of joint projects and holding of joint workshops were the principal modes of cooperation between the research groups of the two nations .

During the years 1982 and 1983, an additional channel of interaction, known as the Science and Technology Initiative (STI), was negotiated between the two Governments. It was restricted to the areas of Health, Agriculture, Biomass, Monsoon Research, Photo-Voltaic Materials and Mineral Engineering. It functioned independently of the S&T Subcommission, and had a different funding mechanism. In contrast to the Subcommission related projects, which were supported with the US held Rupees in India, the STI programme was funded separately by the two Governments: the Government of India financing the Indian component of co-operation and the US Government taking care of expenditure on the American side. The third and the last phase of STI Programme was concluded in 1991.

During the second half of 1980s, two principal issues surfaced with regard to scientific and technological relations between India and the United States: the future mechanisms of funding when the US held Rupees in India were exhausted, and a lack of agreement on the protection of intellectual property rights (IPR) with respect to the results of jointly executed projects. The latter problem arose from the differing provisions of the American and the Indian national patent laws. As a result, the S&T interaction was, at the instance of the US Government, restricted to themes of basic research only. No proposals having any IPR implication were entertained.

During the years 1992 to 1995, the Indo-US Science and Technology Fellowship Programme provided Indian scientists and technologists with opportunities to get acquainted with advancements in some of the frontier areas, by working for a year in host American institutions. These included the areas of Computer Science, Advanced Materials, Robotics, Turbo-machinery, Instrumentation, Space Technology and Biotechnology.

A more recent development has been the establishment in June 2000, of the Indo-US Science and Technology Forum. The Forum aims *to facilitate and promote the interaction in India and the United States, of government, academia, and industry in science and technology and focus on issues of common concern and activities of mutual benefit while exploring trends in S&T*.

Vietnam: The S&T cooperation between Vietnam and India, which started in the early 1980s, is a good example of collaboration between two countries, neither of which was scientifically very advanced. India was itself an economically developing nation, which had a long way to go in fulfilling its own scientific and technological goals. But, as a result of the foresight and determined policies of the Government, it had despite all odds, taken resolute steps in building up a sizeable base for education and training of its scientific and technical manpower, for launching research and development programmes, and for setting up industrial units in some of the core sectors of importance to the country.

With the availability of its infrastructure and experience, India was in a position to assist Vietnam, by training some of its technical personnel in areas



Photo: A.K. Kalra, DST

Indian sample of 8-row manual rice tarnsplanter for development in Uzbekistan under the Indo-Uzbek S&T Cooperation activities.

that were relevant to that country's needs. The interests of the Vietnamese trainees were mostly in disciplines of an applied nature, related to the needs of building infrastructure and related facilities in their own country. To provide an indication of the kinds of training they received in India, we mention the following areas : Fabrication of Railway Carriage, Irrigation Techniques, Tissue and Cell Cultures for Propagating and Improving Medicinal Plants, Low Cost Building Materials, Environment Management, Fruit Conservation, Remote Sensing, New Energy Sources, Informatics and Computers, Library Science, and Chemistry of Natural Products.

Utmost cooperation on the part of the various host institutions in India contributed to the success of these training programmes.

Regional Cooperation.

The special features of the Indo-EEC and the SAARC programmes in S&T are briefly described here.

European Economic Community (EEC): The shaping of relations between India and the EEC was a novel experience for both sides. Though the Government of India had bilateral relations with some of the individual members of the European Community, what the Indo-EC forum sought to develop was a framework of cooperation which would reflect the Indian interests on the one hand and the collective interests of the members of the EC, on the other. The Government of India was to transact business with the European Economic Commission in Brussels, rather than with the Governments of the individual countries. This implied that, in principle, a collaborative project could be developed between an Indian research group with two or more research teams in separate member nations of the Community, or, that a joint programme could be formulated with a research group within a laboratory of the EC, which was otherwise outside the purview of a bilateral arrangement with any of the member countries of the Community. The European Commission had, on its part, to look after the interests of its member countries in whatever programmes were agreed upon with the Indian side.

The Indo-EEC co-operation in S&T began to take place under two separate programmes of the Commission, viz., 1. International Scientific cooperation (ISC), and 2. Science and Technology for Development (STD). ISC was a purely bilateral arrangement which EEC had with the various non-EEC countries, while STD was a multi-partner mechanism in which a country like India was one of the collaborating partners. There were three sub-classifications under the STD Programme, and India was a partner country only in STD-II and STD-III, which dealt with cooperation in the areas of

Agriculture, Life and Medical Sciences. Both these Programmes were closed down by the EC in 1994. From 1985 to 1994, ISC approved 39 projects; during 1987-1991, in all 11 projects were supported under STD-II, and during 1991-1994, in all 19 projects took place under STD-III, with India as one of the partner countries. Three joint workshops were also organized in India during this period.

Another important segment was the award of the EEC-Postdoctoral Fellowships to Indian scientists, for working in laboratories in EEC member countries. Of the 40 fellowships funded annually, 20 were awarded to young scientists for a period of one year and 20 to more senior scientists for a period of six months. About 130 fellowships were availed by the Indian scientists between 1991 and 1994, in the areas of Agricultural Sciences, Biotechnology, Chemical Sciences, Engineering Sciences, Earth-Atmospheric-Marine Sciences, Life Sciences, Physical and Material Sciences, Mathematics, Computer Sciences, and New and Renewable Sources of Energy.

In more recent years, India became partner in a number of projects in the Framework IV Programme, with 100 per cent grants provided by the EC. It was mandatory for these projects to involve two partners from the EC and two from the Developing Countries. From the Indian subcontinent, the latter two could in some cases be both from India.

South Asian Association for Regional Cooperation (SAARC):The idea of strengthening cooperation among the seven South Asian countries, of Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, and Sri Lanka, was first discussed at the meeting of their Foreign Secretaries in Colombo in April 1981. It was agreed to set up Study Groups consisting of national representatives in respective areas of regional interest, to exchange views on issues of common concern, and to recommend possible measures for dealing with them through a suitably constituted forum. The concept of South Asian Regional Cooperation was thus born.

The field of science and technology was considered to be of regional importance with 14 areas of interest identified. Cooperation was to take place through exchange of information, exchange of experts, training programmes, scholarships, seminars and workshops, and joint projects of regional nature. To facilitate such interactions, Pakistan, in its capacity as the first Coordinator country, brought out a well prepared and informative document, entitled South Asian Regional Cooperation Directory of Scientific and Technological Activities, prepared on the basis of the inputs received from the seven countries.

The first Summit of the seven nations took place in Dhaka in December 1985. This meeting marked the birth of the South Asian Association for Regional Cooperation (SAARC), with the adoption of a Charter establishing this Association. The Charter enunciated the Objectives of the Association, and its Principles and General provisions.

At its annual meetings, the SAARC Technical Committee on S&T cooperation review the activities of the previous year, considers the proposals in different areas from the member countries, and recommends a Calendar of Activities for the following year. Its recommendations are considered, for approval, by the Standing Committee of the Foreign Secretaries. The meetings of the Technical Committee take place in the capitals of the member countries by rotation, with each country serving as host for two years in succession. The salient features of the SAARC programmes have been: 1. the organization of seminars and workshops; 2. the training of S&T personnel; 3. the preparation of state-of-the art reports; and 4. joint projects

Science and Technology is one of the 12 areas of cooperation comprising the SAARC Integrated Programme of Action, with each of the other areas having its own Technical Committee. These activities are looked after by the SAARC Secretariat which was established in Kathmandu in January 1987. The Secretariat coordinates and monitors the implementation of SAARC activities, services the

meetings of the Association, and serves as the channel of communication between SAARC and other international organisations. The Secretariat is headed by a Secretary General, who is nominated by one member country in turn.

Multilateral Cooperation:

UN Agencies: India has interacted with several Agencies of the United Nations, through participation in their respective programmes. These have included, among others, Development Assistance Scheme of the Food and Agriculture Organization (FAO); International Oceanographic Commission, and the Man and Biosphere Programme of UNESCO; projects supported by the United Nations Development Programme (UNDP) in a number of areas in agriculture, environment, science and technology, and health and family welfare; programmes relating to control and eradication of a number of diseases with the assistance of World Health Organization (WHO); hosting the regional meteorological training centres of the World Meteorological Organization (WMO), and serving as one of the Regional Meteorological Centres of WMO's Global Data Processing System.

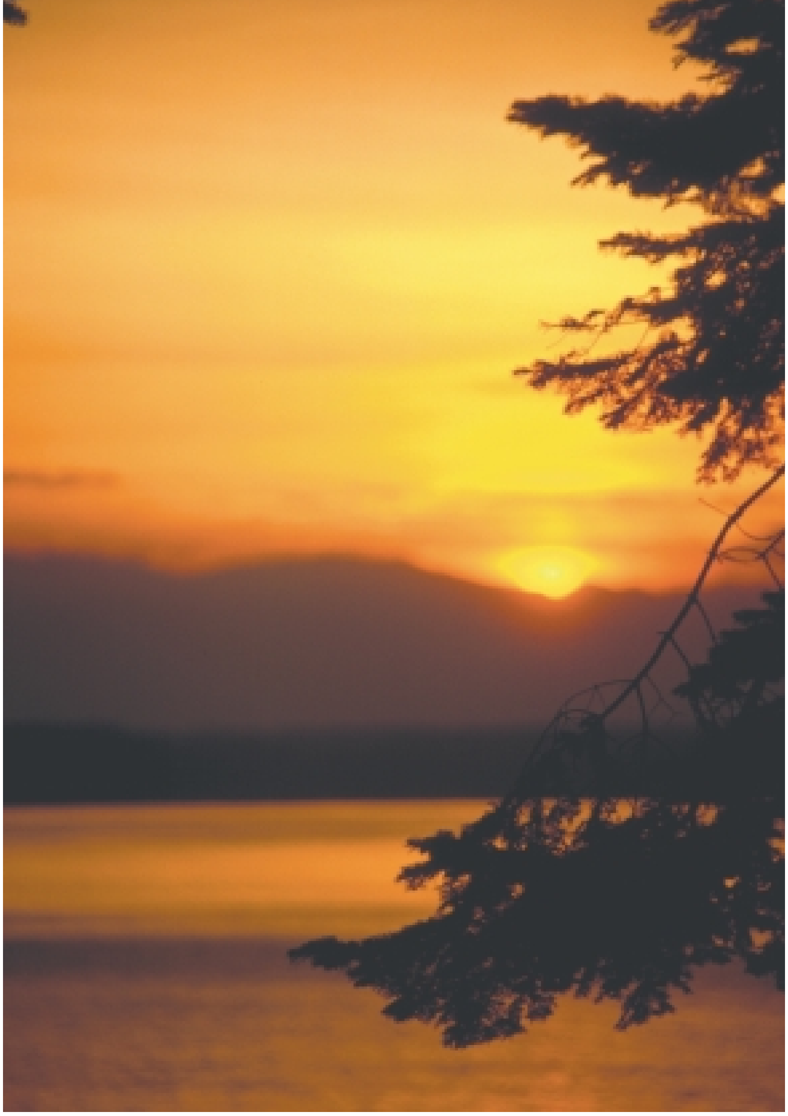
Third World Academy of Sciences (TWAS) : The Indian scientific community has an active relationship with the TWAS. Launched by the Secretary General of the UN in Trieste, Italy, in 1985, the responsibility for administering its staff and funds was taken up by UNESCO in 1991. The objectives of the Academy are: (i) to promote excellence of scientific research in the South; (ii) to provide promising scientists from the South with research facilities for advancement of their work; (iii) to facilitate contacts between scientists and institutions of the South; and (iv) to encourage South-North cooperation between individuals and centres of scholarship.

Two important achievements of TWAS have been 1. the establishment of the Third World Network of Scientific Organizations (TWNSO) in 1988, and 2. the establishment of the Third World Organization for Women in Science (TWOWS) in 1993. The TWAS South-South Fellowship Scheme is aimed at promoting contacts between research scientists in the South and to further relations between their scientific institutions and has been well utilized generally.

The members of TWNSO in India include: Indian National Science Academy, National Academy of Sciences, Council of Scientific and Industrial Research, National Academy of Medical Sciences, and National Academy of Agricultural Sciences.

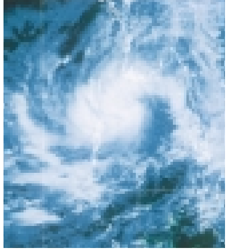
TWAS has supported a large number of research projects in Biology, Physics, Chemistry and Mathematics in India, supported Scientific Meetings in the country and awarded several South-South Fellowships to scientists

The revolution in the field of information technology has made the world a smaller place to live in. At the same time, the economic and strategic interests of individual countries have given rise to newer and changing norms of relationship amongst them. It is inevitable that these considerations should also apply to their dealings in the fields of scientific research and application. The future years should witness newer forms of cooperative linkage emerging between nations. India, with its diverse and valuable experience of the past few decades, is ready to play an active part in this future enterprise.



LOOKING AHEAD

Considering the size and multitudinous problems, India has made significant progress in several spheres: agriculture, irrigation, atomic energy, space, information and communication technologies and science education. To ensure ecological security, provide safe drinking water, better health, employment, peace and equity, we have to utilize science and technology more effectively. In this section a foremost and passionate practising scientist of India reviews the advances and suggests the need for a strategy for the future, using the combined strength of science and socio-economic sectors.



CHAPTER XXXVIII

LOOKING AHEAD

PROLOGUE

When we gained independence in 1947, we had the faith that the country will emerge to be a progressive country, which was economically sound and where social justice prevailed. As articulated by Mahatma Gandhi, true freedom meant wiping out hunger, poverty, unemployment, bridging the gulf between the rich and the poor, banishing communal strife and ensuring that millions of Indians participated in nation building. These hopes were enshrined in our constitution as well. Our constitution under the Directive Principles of State Policy states : *The State shall, in particular, direct its policy towards securing (a) that the citizens, men and women equally, have the right to an adequate means of livelihood; (b) that the ownership and control of the material resources of the community are so distributed as best to subserve the common good... (article 39). The State shall endeavour to provide, within a period of ten years from the commencement of the constitution, for free and compulsory education for all children until they complete the age of fourteen years (article 45). The State shall regard the raising of the level of nutrition and the standard of living of its people and the improvement of public health as among its primary duties... (article 47). The State shall endeavour to organize agriculture and animal husbandry on modern and scientific lines... (article 48).*

India is one of the few countries which recognized, from the very beginning, the importance of science in national development. *The Scientific Policy Resolution* moved in the Parliament on March 4, 1958 by Jawaharlal Nehru, clearly states that we have to secure for the people of the country all the benefits that can accrue from the acquisition and application of scientific knowledge.

It is universally accepted today that the use of scientific knowledge has improved the quality of life all over the globe. This great benefit to humankind is exemplified by the increase in life expectancy, increased agricultural output and availability of cures for many of the diseases. The myriads of scientific discoveries and technological developments have indeed affected humankind in a big way. We in India have had scientific traditions for centuries, and the application of modern scientific knowledge has helped us to overcome many difficult problems. For example, the agricultural revolution and the eradication of smallpox and control of many other diseases have brought in considerable relief to our population. Today, we are not only self-sufficient in food, but have also performed well in the production of milk, vegetables and fruits. Wherever our scientists have been assigned well-defined tasks, the results have been truly remarkable. Our accomplishments in atomic energy and space being typical instances. In the last 50 years, we have built a number of scientific and educational institutions and the country has considerable technical personnel.

Despite the progress made in the last five decades, the country still faces many challenges. We have a high percentage of illiterates, and diseases such as malaria and tuberculosis continue to plague our people. Safe drinking water is not available in large parts of the country. Malnutrition is rampant and is affecting the physical and mental growth potentials of our population. Clearly, there is a need for more effective utilization of science and technology for the

progress of our nation and for improving the overall quality of life of our citizens. We require planning for science, and science in planning. We should recognize, however that solutions to the various problems faced in the country do not depend on science and technology alone. There is need for political will as well as proper organization and planning in the socio-economic sectors.

The need to integrate socio-economic planning with science & technology planning has been stressed over the years. The first meaningful effort in this direction was made by the National Committee for Science and Technology (NCST) during the 1970's. The NCST prepared the first science & technology plan with an agenda for action. Since then, there have been other bodies, in particular the Science Advisory Committee to the Cabinet (SACC) and the Scientific Advisory Council to the Prime Minister (SAC-PM) which have attempted to draw up programmes and plans for science and technology in the country. Much of what has been said in the approach papers and other documents produced by these bodies continue to be relevant today. While there has been some success in integrating science & technology planning with socio-economic planning, there is still much to be done. Many important scientific bodies such as the Science and Engineering Research Council (SERC) owe their creation to NCST. SACC was responsible for establishing the Departments of Biotechnology and Ocean Development. A technology policy was also formulated during the 1980's by SACC. Important structures such as the Technology Information Forecasting and Assessment Council (TIFAC) were established by the SAC-PM and Scientific Adviser to the Prime Minister during 1985-89, when many important national technological missions such as drinking water and universal literacy were launched.

Sustainable livelihood is the important need of all our citizens. While planning for science and technology (S&T), therefore, we cannot forget that we have to justify the trust placed by the society on the scientific community. The society should have a reason to support science in the country and it is important to demonstrate the effective role of science in improving the conditions and standards of living specially of the underprivileged. In such planning, we must consider the various possible development alternatives and adopt such policies and programmes as would promote sustainable development. Instead of following beaten paths defined elsewhere, the Indian situation has to be the main guiding force. Such an Indian approach to development is necessary to reduce unemployment and ensure social justice. We have to play a significant role in the major revolutions of this century such as the gene revolution, materials revolution, information technology and communications revolution and ecotechnology revolution. With well-directed efforts, it should indeed be possible to improve the overall quality of life of our people in the near future. In what follows, we briefly examine some of the dimensions in planning S&T in this vast democratic country. I deal with the infrastructure needs first since they are essential for the development of both urban and rural India.

Infrastructure requirements

A serious problem that we face in making national development plans relates to infrastructure in all its aspects. Infrastructure includes the core sectors of energy, transportation, communications and education.

The relationship between energy and population is conditioned by factors such as economic growth rate, demand for food, changes in living conditions, availability of technologies and capital. We have to evolve a proper energy policy wherein we define how the country should make use of the different sources of energy. We have not adequately made use of alternative energy sources, in particular solar energy. India should be a leader in solar energy research, and this requires special attention. There is a need to adopt an energy strategy which would have a high priority for development of renewable sources of energy as well as for energy conservation and efficient use.

The future demand for transportation will be governed by several factors which include income

growth, energy supply, urbanization, environmental norms and pressures from rural and remote areas. The need for much better public and intermodal transportation systems will acquire increasing importance. Our roads and railways will have to be able to satisfy the increasing demands of industry and society, particularly for the transportation of food and other goods. An air transportation strategy using medium-sized aircraft should be considered as a means of travel to isolated places.

There is much to be done in obtaining the full benefits by the use of modern information technology. It is not only useful as a means of communication among institutions and people, but also as a means to integrate the country. We have to network all our scientific, industrial and educational institutions. A proper communications facility would give greater confidence to people in rural India and empower them in the true sense. The new information technology policy of the government addresses many of the current concerns.

Education is an integral part of the infrastructure. Without a proper education base, no plan can succeed. In addition to the eradication of illiteracy, inculcation of scientific temper amongst the masses should get priority. A proper scientific awareness will trigger the participation of a majority of our citizens in the development process and enhance their ability to tackle new situations. Facilities in educational institutions need immediate attention. Strengthening the education sector will give us a strong knowledge base which can be directly utilized to create wealth. It is necessary that the allocation for the education sector is at least doubled reaching 6% of the GDP in the next year or two. A sound policy for allocation of funds to different aspects of educational development is needed. It is essential that there is parallel progress in the primary and the higher education sectors.

Pressing Problems

While several kinds of efforts in science & technology are required today, the most important of them are those addressed to the solution of the pressing problems of society. These include population, food, shelter, health and nutrition.

India's population is expected to be about 1,500 million by 2050 and the problem of food security in the country may become serious in the years to come. It is likely that we will have to produce around 350 million tonnes of food by the middle of next century. The increasing population will exert severe pressure on land, forests and water resources. If we continue to use these resources at the present rate, there can be a large gap between food grain production and demand. A new approach to resource management is obviously necessary.

Although provision of shelter for the people is enshrined in our constitution, it has not received the attention it deserves. The estimated shortage of housing in 1990 was about 30 per cent of the need. The living conditions are far from satisfactory. Nearly 40 per cent of our population live in one-room tenements and another 30 per cent in two-room dwelling units. Only 75 per cent of urban and 30 per cent of the rural households receive electricity. Initiatives are needed to correct these major deficiencies.

The health of a person is largely dependent on the nutritional input. Nutritional inadequacy arises either due to poverty or environmental degradation. Undernutrition and malnutrition also contribute to mortality rates. Malnutrition and maintenance of health pose serious problems, particularly in the rural parts of the country. There are many diseases unique to India which demand considerable research effort.

Health care and services play a significant role in population control, just as education and economic well being. Nearly 70 per cent of the public sector outlay for health is spent in urban areas, where substantial private sector facilities exist. The nature of training and technology required for health care in rural areas would require a totally different approach than what prevails. Careful thought has to be given to find ways to exploit our strengths in indigenous forms of medicine, instead of total dependence on the western system.

Competitiveness

Besides tackling the pressing problems of the society and those related to infrastructure, science and technology have to be fully exploited to make the country competitive. The technology base of the Indian industry has to be significantly improved and innovation has to play a greater role in our industry. The art of transforming knowledge into wealth has to be learnt by all concerned and this can happen only when we fully appreciate the role of the knowledge-base. Industry has to invest considerably more on R&D, innovation and humanpower training. There has to be emphasis on engineering design and in the accumulation of intellectual property. Greater attention has to be paid to knowledge-based industry where India can become a world leader. For example, in the software area our aim should be to get around 4-5% of the world business.

Long-term planning in technology has severe limitations. It is important to be vigilant about new and unexpected developments in technology and the likely areas in science that are expected to yield path-breaking technologies. Support for fundamental research is important because new technologies will be based on science at the cutting edge. Unless we are leaders in science, it is unlikely that we will be competitive in technologies of the future.

The recent trend when young people are mainly attracted to business and banking has to be reversed. Young talent has to be attracted to take up careers in science and engineering.

The Government has to take the major responsibility to support S&T as well as higher education in the country for some years to come. Industry may eventually help in this direction, but this will take some time. The Government has a crucial role in this transition period. In order to sustain the existing talent and for inducting new capabilities to meet new challenges, there should be a clear declaration of support for science and technology. Such a policy commitment should be demonstrated by increasing the present level of support of science from around 1% of the GDP to 2 or 3% within a time frame.

Successful scientific efforts in the country have resulted when the programmes have clearly defined targets and there is autonomy and accountability. They have also demonstrated the positive effects of multi-institutional linkages. These factors should be kept in mind when supporting scientific research.

Epilogue

In conclusion, renewed efforts are required in areas of national priority where science and technology should play even a greater role. It is not difficult to achieve a consensus on priority areas such as food security, housing, health and nutrition, energy security, transportation, communications, education and information technology. For each of these priority needs, specific goals, time-bound targets and programmes have to defined with a sense of urgency. For example, we should be able to remove illiteracy, malaria and malnutrition in the next ten years. Because of the increasing competition as well as increasing population, we will face even bigger challenges in the years to come. We should become economically strong by the year 2020 by ensuring food security, a balanced energy economy and leadership in chosen sectors of science, technology and industry. There is talent in the country to accomplish the targets, and all that is needed is to give a direction to our efforts and to motivate people to take up the tasks.

What has been said above applies equally to most of the developing countries. The next 20 to 30 years will be a trial period for all of us and we have no choice but to move forward. Let us forget our differences and concentrate on the common good, and the well-being of all our peoples. While north-south cooperation is important, south-south cooperation will be of even greater significance in the years to come. There will be many problems and difficulties in accomplishing our tasks, but WE SHALL OVERCOME !

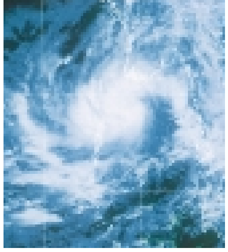
An Academy of Science can do a great deal by educating public opinion, undertaking particular problems, and bringing out scientific workers in various fields for discussion and cooperative research. But the main function of the Academy should be towards cultural improvement by contribution to human knowledge.

- Meghnad Saha



INDIAN NATIONAL SCIENCE ACADEMY

Science academies play a crucial role in promoting, recognizing and rewarding excellence. Another important task is to publish journals, organize scientific discussions and bring out proceedings and monographs. The academies promote public awareness and understanding of science. Acting as links between the scientific community and the planners, they advise the governments on critical issues. Importantly they serve as forums for interaction among scientists within and outside the country. In this section the growth of the Indian National Science Academy and its functions are highlighted.



CHAPTER XXXIX

INDIAN NATIONAL SCIENCE ACADEMY

FOUNDATION

The Indian National Science Academy (INSA) is the apex body of Indian scientists representing all branches of science and technology. Its objectives encompass promotion of science in India including its application to national welfare, safeguarding the interests of the scientists, establishing linkages with international bodies to foster collaboration and expressing considered opinion on national issues. The foundation of the Academy in 1935, originally as the National Institute of Sciences in India (NISI), was the outcome of the joint endeavours of several organizations and individuals. The Indian Science Congress Association (ISCA), the active association of Indian scientists of the time, played a leading role in its genesis.

Towards the end of the 1930's, the Government of India addressed letters to various provincial Governments, scientific departments, learned societies, universities and to the ISCA seeking their opinion on the desirability of forming a National Research Council which would adhere to and co-operate with the International Research Council and its affiliated Unions. This proposal was considered by various eminent scientists whose views regarding the composition and functioning of such a national council were put up in the form of a resolution to the ISCA.

In May 1933, an editorial was published in the journal, *Current Science*, outlining the views of its editors about the founding of an Indian Academy of Sciences. In September of the same year, the Board of Editorial Cooperators of *Current Science* issued a questionnaire on the subject and invited opinions of Indian scientists. The scientists of Kolkata who jointly considered the questionnaire and in view of the accepted position of the ISCA as an all-India scientific body, made a formal request that all proposals for establishing the Academy be included in the agenda of the General Committee of the ISCA for discussions at its Mumbai session.

In this session, Meghnad Saha, in his Presidential address, referred in detail to the proposal to form an Indian Academy of Sciences and suggested a scheme for its formation on the model of the Royal Society of London. It was thereafter discussed in a special meeting of the General Committee of the ISCA on January 3, 1934. The General Committee constituted the Academy Committee. The report of the Academy Committee was placed by L.L. Fermor, President of the 20th Session of the ISCA before a Special Meeting of the Joint Committee, on January 3, 1935. The recommendations of the Academy Committee were accepted after a unanimous resolution by the ISCA and the foundation of the National Institute of Sciences of India (NISI), as an all-India body of scientists, was thus laid. An inaugural meeting of the NISI was held on January 7, 1935 at Calcutta University. The Institute started functioning with its Headquarters at the Asiatic Society of Bengal, 1 Park Street, Kolkata, from that day.

Inaugural Meeting

The Inaugural Meeting of the National Institute of Sciences of India was held in the Senate Hall of the University of Calcutta at 5.30 P.M. on Monday January 7, 1935. J.H.Hutton, President of the Indian Science Congress, was in the chair, supported by L.L.Fermor, President of the National Institute of Sciences of India. His Excellency Sir John Anderson, Governor of Bengal, had been invited to inaugurate the National Institute.

A large number of scientists had gathered from all parts of India. The eminent public men of Kolkata present at the meeting included Judges of the High Court, Members of the Government of Bengal, the Mayor of Kolkata, the Vice-Chancellor of the Calcutta University, representatives of the educational and scientific institutions, the learned societies, and the Chambers of Commerce of Calcutta, University teachers and many others. Among those present mention may be made of: Sir Harold Darbyshire, Hon. R.N.Reid, Hon. Sir B.L.Mitter, Hon. Nawab Bahadur, Sir K G M Faroqui, Hon. Khan Bahadur Abdul Aziz, Syama Prasad Mukerjee, Hon. Kunwar Jagadish Prasad, Nalini Ranjan Sarkar, and 62 (out of 125) Foundation Fellows of the Academy.

J.H Hutton, while inviting His Excellency Sir John Anderson, Governor of Bengal, to inaugurate the Institute, stated: *Your Excellency, a year ago under the guidance of Professor Saha, the Indian Science Congress appointed a Committee to draft a constitution for and to take the necessary step to bring into being, a national scientific body which should perform for India some of those functions which the Royal Society performs for Great Britain. That Committee, not without meeting difficulties, has carried out the work for which it was appointed, and the constitution drafted has been accepted by the Indian Science Congress. It remains to call the body into existence, and I have the honour, as representing the Indian Science Congress in 1935 of asking Your Excellency to inaugurate the National Institute of Science of India.*

John Anderson delivered a brief address and then inaugurated the National Institute. Thereafter L.L. Fermor, President of the National Institute of Sciences of India delivered his Inaugural Address. Both these addresses are preserved in the archives of the academy. After the President's address, S.P. Agharkar, one of the Secretaries of the National Institute, read out the list of names of the learned bodies that had sent representatives and messages of congratulations to the National Institute on its inauguration. Good wishes for the success of the National Institute had been received by the President from the following members of the Governor General's Council: the Hon. Sir James Grigg, the Hon. Sir Fazl-i-Husain, and the Hon. Sir Frank Noyce and also from three eminent scientists of India, Sir J.C. Bose, Sir Martin O.Forster and Sir P.C.Ray.

The historic meeting was concluded by S.P.Agharkar proposing a vote of thanks followed by a joyful celebration.



The Convention Centre and the Jubilee building of the Academy premises.

The issue of Government recognition of the NISI as the representative body of Indian scientists came up ten years after its foundation. After due deliberation and discussions, the Government decided to recognize the National Institute as the premier scientific society representing all branches of science in India in October, 1945. The Headquarters of the National Institute were moved to Delhi University to a large hall presently located in the Department of Botany in May 1946. The Government commenced providing increased grants to the Institute to meet expenses on travel, publications, research fellowships, and for allocating grants-in-aid to other scientific societies for bringing out their publications. A capital grant for the building of the Headquarters was also sanctioned in 1948. The foundation stone of the building was laid by Prime Minister Jawaharlal Nehru on April 19, 1948. The building was ready for occupation in 1951 on Bahadur Shah Zafar Marg, New Delhi. NISI was designated the adhering organization to the International Council for Science (ICSU) on behalf of the Government of India in January, 1968.

The name of the National Institute of Sciences in India was changed to Indian National Science Academy (INSA) in 1970.

INSA's Objectives

The main objectives of the Indian National Science Academy are:

- Promotion of scientific knowledge in India including its practical application to problems of national welfare.
- Co-ordination among scientific academies, societies, institutions, the Government scientific departments and services.
- To act as a body of scientists of eminence for the promotion and safeguarding of the interests of scientists in India and to present internationally the scientific work done in the country.
- To act through properly constituted national committees, in which other learned academies and societies may be associated, for undertaking scientific work of national and international importance which the Academy may be called upon to perform by the public and by the Government.
- To publish such proceedings, journals, memoirs and other publications as may be found desirable.
- To promote and maintain the liaison between sciences and humanities.
- To secure and manage funds and endowments for the promotion of science.
- To perform all other acts that may assist in, or be necessary for the fulfilment of the above mentioned objectives of the Academy.

Organization and Fellowship

The Academy consists of Foundation Fellows, Fellows and Foreign Fellows.

a Foundation Fellows were those 125 scientists who had accepted nomination before the inauguration of the Academy.

b Indian citizens who are elected according to the rules of election are admitted as Fellows.

c Foreign Fellows are those persons who are eminent for their knowledge of, or contributions to science, or the welfare thereof, and domiciled outside the territorial limits of India, who have in

some way contributed or can contribute to the progress of science in the country. Citizens of all countries other than India are eligible for the Foreign Fellowship of the Academy.

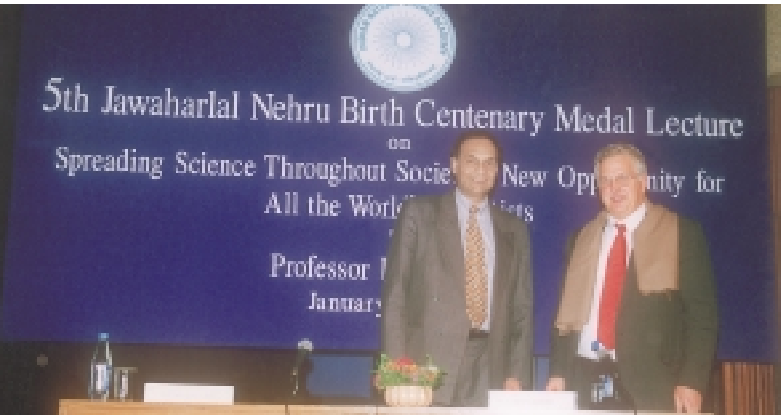
The task of administration, direction and management of the affairs of the Academy is entrusted to a Council composed of the Board of Officers of the Academy, namely, a President and six Vice-Presidents and 20 other Fellows making a total of 27. The Vice-Presidents have collective as well as individual responsibilities assigned for various categories such as: Fellowship Affairs; Science Promotion; Resource Management; International Affairs; Publications/Informatics; and Science and Society. In addition, there is provision for additional members of the Council, one each to be nominated by the co-operating Academies i.e., the Asiatic Society, Kolkata; the National Academy of Sciences (India), Allahabad and the Indian Science Congress Association, from amongst the Fellows of the Academy. Further, The Government of India nominates one member from amongst the Fellows of the Academy as its representative on the Council.

The Council oversees all activities of the Academy through various standing committees, advisory committees and sub-committees appointed for the purpose. The Council deals with all decisions in relation to election of Fellows, Foreign Fellows, selection of INSA Young Scientists, INSA Medal Awardees, matters relating to local chapters and changes or modifications of the rules and regulations of the Academy and other matters as may be referred to the Academy from time to time.

Election of Fellows: Nomination for election to Fellowship of the Academy is proposed, seconded and supported by a minimum of four Fellows. Of these, at least three should have personal knowledge of the scientific attainments of the nominee. The valid nomination papers are scrutinised by concerned discipline-wise Sectional Committees and/or interdisciplinary committees and their recommendations are considered by the Council. The list drawn up by the Council, not exceeding 30, is circulated to the Fellowship for

Indira Gandhi arriving to inaugurate the Golden Jubilee Celebrations of the Academy in January 1984.







Top: Professor Bruce Alberts, President, US National Academy of Sciences delivered the 5th Jawaharlal Nehru Birth Centenary Medal Lecture in January 2001.
Bottom: A young scientist recieving the INSA Medal from the then President of the Academy.

voting. The Fellowship of those elected becomes effective on January 1 of the ensuing year.

In addition to the election of Fellows which is restricted to persons holding Indian citizenship, Foreign Fellowship proposals are received from the Fellowship. These are considered by the Council whose recommendations in this regard are circulated to the Fellowship for voting.

A special provision in the rules of the Academy enables election of outstanding persons who have rendered conspicuous service to the cause of science or whose election to the Academy would be of signal benefit. This is exercised by the Council only in exceptional cases. So far the Academy had the honour of electing Jawaharlal Nehru, Indira Gandhi, J.R.D. Tata and Satish Dhawan as Fellows in this category.

Activities

Local Chapters: Besides the activities at its headquarters, the Academy functions in other parts of the country through its Local Chapters located in nineteen cities. Fellows residing in the vicinity of these cities attend meetings of the Local Chapters. These Chapters provide financial assistance for arranging lectures by eminent scientists and for organizing programmes of popularization of science and inculcation of scientific temper among the public. A few of the INSA Medal Lectures are also delivered at the Local Chapters.

Academy Awards and Lectures: Since 1950, the Academy has been conferring medals and awards to eminent scientists in various disciplines. The Academy has instituted 54 medals and endowment lectureship of different categories. On an average, around 20 awards are conferred every year. The recipients of these various medals/lectureships are expected to deliver lectures on subjects of their choice.

INSA Medal for Young Scientists: The INSA Young Scientists Award (instituted in 1974), considered to be the highest recognition of promise, creativity and excellence among young scientists, below the age of 32 is made annually to those distinguished for these attributes as evidenced by their research work carried out in India. This was the first initiative in India to encourage promising young workers. So far, 401 young scientists have been recognized. Many of them have established a rewarding scientific career and are continuing to make outstanding contributions, receiving further recognition in India and abroad.

Each awardee is considered for start-up research support. Also, the awardee, within five years of receipt of award, is encouraged for a visit abroad with full support for presenting a research paper in

an important conference, and/or for participating in collaborative/training research project. As part of their career development, those young scientists who have been unable to obtain suitable employment, may be considered for an interim Fellowship.

Science and Society Interface: The Academy has taken the responsibility of expressing its opinion on scientific issues concerning society at large and has, in the process, helped in the public understanding of science. Over the years, through discussions and analyses, the Fellows of the Academy have expressed opinions on specific issues for the benefit of the scientific community, policy planners and society at large. Mention may be made of a few issues, such as: the Concern for Conserving the Silent Valley; Problems of Failure of Irrigation Structures, Dams and Strata under Reservoir; Higher Education in Science; Health of Science in India; Energy Options in India; Intellectual Property Rights in Biology; Emerging Communication Technology; Guidelines for Care and Use of Animals in Scientific Research; Compulsory Iodination of Salt to Prevent Iodine Deficiency Disorders; and a report on Transgenic Plants and World Agriculture. A report on the last theme was prepared under the auspices of the Royal Society of London, the US National Academy of Sciences, the Indian National Science Academy, the Brazilian Academy of Sciences, the Chinese Academy

Professor D.S. Kothari, Past-President of INSA, distributing prizes to school children on the National Science Day.



of Sciences, the Mexican Academy of Sciences and the Third World Academy of Sciences.

The Academy organizes a series of popular lectures for the benefit of the public at Delhi and at other local chapters. These lectures are very popular among school children who have opportunities for question-answer sessions. A major event is the National Science Day held on February 28 every year, to commemorate the discovery of the Raman Effect.

Crossing Barriers: International Collaboration Among Scientists

International Council for Science (ICSU): ICSU as body representing world's scientists has had a chequered history. Through the efforts of scientists in European countries an International Association of Academies (IAA) was started in 1899. Its objectives were to initiate and promote scientific undertakings of common interest and to facilitate scientific interactions among the various countries. World War I interrupted IAA. A fresh beginning was made in 1918-19 to found the International Research Council (IRC) with membership open to a National Research Council of any country of the world. In 1931 the name of IRC was changed to International Council for Scientific Unions (ICSU). After 68 years it was renamed International Council of Science but the acronym ICSU was retained. The then Government of India formally joined IRC and five of its associated unions viz Geodesy and Geophysics , Geography, Astronomy, Biological Sciences and Radio-Telegraphy in 1930. This programme was eventually transfered to INSA in 1968.

ICSU is a non-governmental organization comprising 20 international scientific unions, 66 national members, 17 scientific and four national associates. Since its creation in 1931, ICSU has pursued a policy of non-discrimination, affirming the rights of all scientists throughout the world -- without regard to race, religion, political philosophy, ethnic origin, citizenship, sex or language -- to participate in international scientific activities.

The principal objective ICSU's is to encourage



Some members of INSA delegation visiting Chinese Academy of Sciences in July 1986.

international scientific activity for the benefit of humankind. It is implemented through initiating, designing and coordinating international scientific research projects. The members of the ICSU family organize international conferences, congresses, symposia, summer schools and meetings of experts in various parts of the world. General Assemblies and other meetings are also held to decide policies and programmes. Committees/Commissions of ICSU are created to organize studies in multi-disciplinary and trans-disciplinary fields which are not completely covered under the aegis of any one of the Scientific Unions, such as space and environment. The main Secretariat of ICSU is located in Paris.

India through INSA adheres to ICSU and 18 of its member unions and 10 interdisciplinary bodies listed below:

- International Astronomical Union (IAU),
- International Union of Biochemistry and Molecular Biology (IUBMB),
- International Union of Biological Sciences (IUBS),
- International Union of Pure & Applied Chemistry (IUPAC),
- International Union of Crystallography (IUCr),
- International Union of Geodesy & Geophysics (IUGG),
- International Geographical Union (IGU),
- International Union of Geological Sciences (IUGS),
- International Union of History & Philosophy of Science (IUHPS),
- International Union of Theoretical & Applied Mechanics (IUTAM),
- International Mathematical Union (IMU),
- International Union of Microbiological Societies (IUMS),
- International Union of Nutritional Sciences (IUNS),
- International Union of Pure & Applied Physics (IUPAP),
- International Union of Pure & Applied Biophysics (IUPAB),
- International Union of Pharmacology (IUPHAR),
- International Union of Radio Science (URSI),
- Scientific Committee on Oceanic Research (SCOR),
- Committee on Space Research (COSPAR),
- Committee on Data for Science & Technology (CODATA),
- Scientific Committee on Problems of the Environment (SCOPE),
- Committee on Science & Technology in Developing Countries (COSTED),
- Scientific Committee on Solar-Terrestrial Physics (SCOSTEP),
- Scientific Committee on Lithosphere (SCL),
- World Climate Research Programme (WCRP),
- Scientific Committee on Antarctic Research (SCAR),
- International Geosphere-Biosphere Programme (IGBP).

INSA constitutes National Committees for various unions/interdisciplinary bodies and joint initiatives in India. Each National Committee functions for a three-year tenure. The functions of ICSU National Committees are: exchange of ideas and communication of scientific information with related national and international bodies; development of standards in methodology, nomenclature and units; organizing international conferences/congresses /symposia /meetings of

experts and of General Assemblies in India; preparation of Country Status Reports in research activity in specific or related fields; and selection of Indian scientists for participation in international conferences/congresses/symposia and General Assemblies etc. especially sponsored by ICSU and its affiliated organizations.

Non-ICSU Conferences: There are a large number of other international scientific conferences, symposia, workshops, etc. in the fields of medicine, engineering and applied sciences which are organized each year outside the purview of ICSU. These conferences are termed Non-ICSU conferences. The Academy, provides partial financial assistance to scientists for attending some of the important conferences under this category.

The Committee on Science & Technology in Developing Countries (COSTED): COSTED was set up as a special Scientific Comittee of ICSU at the General Assembly held in Mumbai in 1966. In 1993, it was merged with International Biosciences Network (IBN) which was a joint ICSU-UNESCO Programme. The COSTED stimulates and facilitates the participation of scientists and scientific institutions of the developing countries in the activities of International Science & Technology. It helps generate international projects and programmes to help capacity development of developing countries which addresses to problems relevant to their socio-economic and cultural development. INSA has partnership. The Academy has close linkages with COSTED and also has a programme (jointly)with CSIR, DAE, ISRO and COSTED. In providing financial assistance and support to young Indian research workers for participation in International Conferences abroad.

Inter-Academy Collaboration and Exchange Programme: In May 1967, an Indian delegation visited the then Soviet Union to acquaint itself with research and other activities of the USSR Academy and its institutes and to discuss scientific cooperation between the two nations. Both the Governments agreed to set up a joint committee which met in New Delhi in 1968. INSA's President was nominated the Chairman of the Indian Committee for Indo-Soviet Collaboration. Ever since 1968, the Academy has been successfully collaborating with scientific academies/organizations abroad by sharing research experience and scientific information. Such a relationship has been achieved through bilateral exchange of scientists, collaborative research projects, organization of symposia and meetings.

The Academy coordinates the exchange programmes by facilitating contacts of individuals/scientific institutions in India with those of various foreign collaborating countries. Currently, the Academy has signed 19 Bilateral Agreements/Memoranda of Understanding with the organizations listed below:

- Royal Society, London (1972);
- Japan Society for the Promotion of Science, Tokyo (1976);
- Hungarian Academy of Sciences, Budapest (1980);
- French Academy of Sciences, Paris (1983);
- Polish Academy of Sciences, Warsaw (1983);
- National Academy of Science and Technology of the Philippines, Manila (1983);
- Royal Netherlands Academy of Arts & Sciences, Amsterdam;
- Deutsche Forschungsgemeinschaft, Germany (1987);
- Chinese Academy of Sciences, Beijing (1988);
- Royal Nepal Academy of Science & Technology, Kathmandu (1989);
- Korea Science and Engineering Foundation, Seoul (1989);
- Academy of Science of the Czech Republic, Prague (1993);
- Slovak Academy of Sciences, Bratislava (1993);
- Ukrainian Academy of Sciences, Kiev (1993);
- Academia Brazileira de Ciencias, Brazil (1996);
- National Academy of Sciences of the Kyrghyz

Republic (1996);

- Russian Academy of Sciences, Moscow (1996);
- Slovenian Academy of Sciences and Arts, Slovenia (1998); and
- Slovenian Science Foundation, Slovenia (1998).

With the last three named academies, collaborative programmes on identified areas have also been taken up. The Academy has also signed Agreements/Memoranda of Understanding (MoU) with 13 other Academies/organizations for exchange of scientific information, participation of scientists in conferences/ symposia, etc. These are:

- Australian Academy of Sciences, Canberra;
- National Centre for the Scientific Research, Vietnam;
- Academia Nacional De Ciencias Exactas, Fisicas Y Naturales, Argentina;
- Royal Society of Canada;
- Israel Academy of Sciences & Humanities;
- Royal Swedish Academy of Sciences;
- Academia De Ciencias De Cuba;
- US National Academy of Sciences, Washington;
- State Academy of the DPR Korea, Pyongyang;
- Academy of Sciences of Belarus, Minsk;
- Uzbekistan Academy of Sciences, Tashkent;
- Korean Academy of Science and Technology, Seoul;
- Berlin-Brandenburg Academy of Sciences and Humanities, Berlin.

Under international collaboration and exchange programme, visits of scientists have been exchanged under two categories -- short term visits of 2 to 8 weeks and long term/Fellowship visits up to 6 months. Generally, the senior scientists undertake visits abroad for short duration for discussion and interaction with scientists in different institutions and the younger scientists normally engage themselves in longer duration for collaborative research/training, preferably in one institute/laboratory.

Interaction with International Foundation for Science: The International Foundation for Science (IFS) was started in 1972 in Sweden as a non-Governmental body consisting of around 95 scientific academies, research councils and organizations as its members. The Academy is the member organization in India for the IFS. Under this programme, IFS provides research grants to young scientists from developing countries to enhance their capabilities to carry out research in agriculture, biological sciences and chemistry of natural resources. Over the years, some of the leading INSA Fellows have served on the IFS Board of Trustees. A large number of young Indian scientists have benefitted from this programme.

The then President of INSA at the ceremony of signing on the agreement on scientific cooperation with the Vice-Chancellor of the Royal Nepal Academy of Science and Technology (RONAST) in 1989.



Federation of Asian Scientific Academies and Societies (FASAS): The FASAS was born in 1984 in New Delhi. The Academy is a Founder Member Organization of the FASAS in India and has been sponsoring its activities for the promotion of Science and Technology in the Asian region. The Federation includes 14 scientific Academies/ Societies of the Asian region, namely Afghanistan, Australia, Pakistan, Nepal, New Zealand, Bangladesh, China, India,

Malaysia, Sri Lanka, Korea, Philippines, Singapore and Thailand, as its national members. The Federation fosters co-operation and promotes national and regional self-reliance by sharing experiences in the field of science and technology and in promoting beneficial use of science for society.

Linkages with TWAS and TWNSO: The Third World Academy of Sciences (TWAS) is a non-Governmental body founded in 1983 by a group of eminent scientists from the South under the leadership of Nobel Laureate Abdus Salam of Pakistan to promote South-South and South-North Cooperation in the development and application of S&T in the third world. The Academy has close linkages with the TWAS and Third World Network of Scientific Organizations (TWNSO) ever since their inception. In fact, the largest number of Fellows of TWAS are from India and they are actively involved in various programmes, committees and other activities for the realization of the objectives of TWAS and TWNSO. C.N.R. Rao, an eminent Indian chemist and a Past-President of INSA is the present President of TWAS. The Academy is also represented in the TWNSO Council. TWNSO aims to promote integration of S&T aspects of the national development plans of the third world countries and to establish collaborative studies programmes in areas of critical importance.

The Academy has been extending facilities to younger scientists from Asian countries for attending training programmes in Indian institutions for 6 months or more in relevant fields under FASAS and TWAS Programmes. International travel is provided by TWAS or the member organization in the sponsoring country and living expenses are borne by the Academy through the Technical Cooperation among Developing Countries (TCDC) supported by the DST, New Delhi.

The INSA-Royal Society Lecture Series: The Indian National Science Academy and the Royal Society jointly hold one memorial lecture every year, alternately in India and the United Kingdom. The British scientists are invited to deliver the Blackett Memorial Lecture in India, whereas the Indian scientists dive the Sir J.C.Bose Memorial Lecture in UK.

The Jawaharlal Nehru Birth Centenary Visiting Fellowship: In 1989, the Academy instituted the Jawaharlal Nehru Birth Centenary visiting Fellowship to commemorate Nehru's commitment and sustained support to science. This fellowship enables the Academy to project the achievements of Indian science & technology abroad. One fellowship is awarded annually to a distinguished Indian Scientist for delivering a series of lectures abroad and it is not restricted to countries with which the Academy has exchange programme.

INSA-JRD Tata Fellowship: The Academy, jointly with the Sir Dorabji Tata Trust, has instituted the INSA-JRD Tata Fellowship to encourage scientists and technologists from other developing countries to pursue research in Indian scientific research institutions. About 20 Fellowships are likely to be provided annually. The Fellowship will cover to-and-fro airfare, boarding and lodging at the affiliated institution/s and an allowance to cover incidental expenses.

INSA-KK Birla Foundation Asia Science Lectures: INSA in association with the KK Birla Foundation has jointly instituted an 'INSA-KK Birla Foundation Asia Science Lecture' to promote understanding, interaction and a co-opertive spirit in the Asian region by recognizing eminent scientists/persons who have established themselves as leaders in science and technology or an entrepreneur/scholar who has contributed significantly to areas like S&T, education, health, economy, leading to the development of the Asian Region.

Inter-Academy Panel on International Issues: Presidents of 10 academies of science (including

INSA), on the invitation of the Royal Society, London and U.S. National Academy of Sciences, met in 1992 to discuss the possibility of organizing a meeting of science academies to develop a consensus statement on Population and Development. The President of INSA extended the invitation to hold such a meeting in New Delhi. This resulted in *Population Summit* held in New Delhi in October, 1993. This was the first meeting of over 50 science academies from all parts of the world to discuss an issue of global concern. A consensus statement on the subject was finalized at the 'Summit' and was later presented to the UN Conference on *Population and Development* held at Cairo in 1994, by the Past President of INSA on behalf of the World Academies.

The Inter-Academy Panel (IAP) on International Issues was constituted at INSA in 1995, as a follow-up of the 'Population Summit'. Sixty participating Science Academies unanimously recommended the creation of a joint forum for mutual consultation and, where necessary, joint action on S&T issues of global concern. The Panel also participated in the UN Conference on Human Settlements (Habitat II) held in Istanbul, Turkey and also issued a statement on *S&T and Future of Mega Cities* endorsed by 72 academies of the world. More recently, an International Conference was organized in May, 2000 on *A Transition to Sustainability in the 21st Century* at Tokyo, Japan. P.N. Tandon, Past-President of INSA and F. Sherwood Rowland, Foreign Secretary, USNAS are the co-chair of the Steering Committee of IAP.

Inter-Academy Council (IAC): Over the years it has been felt that there is an urgent need for the global scientific community to develop an effective mechanism for delivering timely advice that can utilize the best scientific expertise, while maintaining a character so clearly global that it cannot be dismissed as reflecting the interest of any one nation or a particular block of nations. The Inter-Academy Council (IAC) was therefore created after the Tokyo

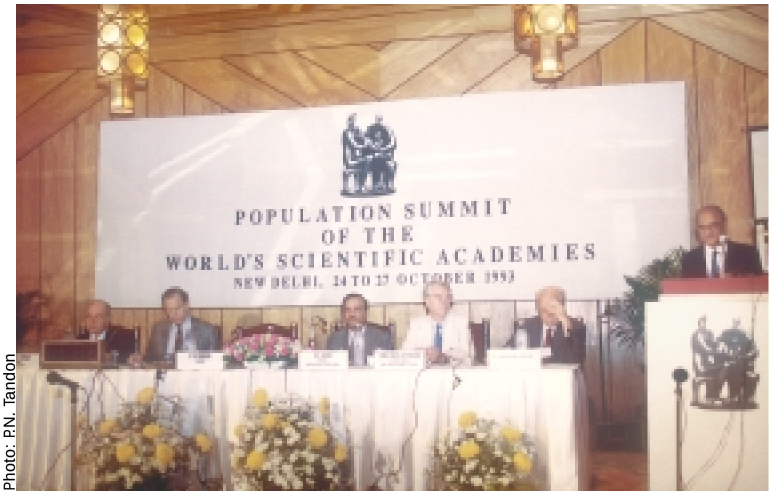


Photo: P.N. Tandon

Population Summit

Conference (May, 2000) as a formal arm of IAP, as a legal entity to provide scientific advice to international organizations on request. The Council consists of 15 Presidents of IAP member academies/organizations. G.Mehta, President INSA, and Bruce Alberts, President USNAS, are co-chairs of IAC. The members of IAC are from Brazil, China, France, Germany, India, Israel, Japan, Malaysia, Mexico, South Africa, Sweden, U.K., USA and TWAS. The President of ICSU and President of the Royal Netherland Academy (the host academy) will be ex-officio members. The IAC Secretariat is based in the Netherlands. Impressed by the success of this venture, it was unanimously decided to establish an informal body to continue such interactions, especially for those issues of global concern where science and technology could play an important role.

Basic Science

Scientific Research & Training: Basic research, a prerequisite for applied research leading to developmental activity, conducted by academic institutions was supported by the Academy in the past. The Academy offered adequate support to research programmes of individual scientists and to interdisciplinary, multi-institutional programmes. In fact, as early as 1946, it instituted the Junior and Senior Research Fellowships which continued up

to 1970. Apart from its own resources, grants-in-aid from CSIR and ICI were placed at the disposal of INSA for funding these Fellowships.This was the first attempt in India to encourage research endeavour in youth. This was followed later by other bodies. With the emergence of major funding agencies in the country, the Academy modified its programme to support individual scientists and diverted its funds to create five positions of INSA Research Professors, support to retired scientists (Fellows of the Academy only), research projects of INSA Young Scientist Medal Awardees and INSA Visiting Fellowship.

The Academy also provides partial financial assistance for holding/organizing international/national conferences, symposia and seminars in India.

INSA Research Professorship: The Academy instituted five research professorships from 1984 onwards, each to be awarded to an outstanding scientist and enable him/her to continue to contribute to the subject of specialization. These prestigious professorships are named after Albert Einstein, Chandrasekhara Venkata Raman, Srinivasa Ramanujan and Satyendra Nath Bose. Besides, one is entitled Golden Jubilee Research Professorship. Each professorship is tenable for five years. Apart from regular emoluments and contingency grant, there is also provision for an appointment of a Research Associate to assist the research professor.

INSA Honorary Scientists Scheme: After trying out a programme of INSA senior scientists (granted to retired Fellows) the Academy has launched the INSA Honorary Scientist Scheme in the year 2000 to utilize the services of Fellows who have formally retired from service but are actively carrying out research in their specialized disciplines and/or are willing to write monographs on topics of importance. The term of an INSA Honorary Scientist is tenable initially for a period of three years and can be extended depending on the plan of work and output. The award carries no honorarium but provides a contingency grant.

INSA Visiting Fellowship: To enable a scientist to conduct advanced collaborative research or receive specialized training in Indian research institutes/laboratories, or to utilize facilities not available in their own institutions, the Academy has instituted this scheme since 1991. The Fellowship enables a scientist to carry out independent or collaborative work for one to six months in a research institution located in an Indian city other than his/her own.

Support to National/International Conferences: The Academy provides partial financial assistance for holding national/international conferences/symposia/ summer/winter schools in India. It also offers token funds for arranging General Assemblies and other ICSU-sponsored international conferences in India or other events recommended by national committees of the various scientific unions of ICSU.

History of Science in India

Recognizing the value of carrying out research on the evolution of science in the growth of Indian civilization and documenting it authentically for posterity, the project of compiling a History of Science in India was started at the Asiatic Society, Kolkata in 1960, under the supervision of the History of Science Board with A.C. Ukil, Past President of the Academy, as Chairman. This programme was sponsored by the then National Institute of Sciences of India (presently INSA). Later on, in order to enlarge the scope of the History of Science Board, an Academy delegation headed by H.J. Bhabha, met the then Education Minister M.C. Chagla which resulted in the founding of the National Commission for the compilation of the History of Science in India in the year 1965. The National Institute started getting an annual grant from Government of India to be disbursed by the National Commission for the work. The name of the National Commission was changes to Indian National Commission for History of Science in 1989.

The Commission's activities cover three

somewhat overlapping periods: Ancient Period till 1200 A.D., Medieval period from 1200 A.D.-1800 A.D. and Modern period from 1801 A.D. onwards.

The functions of the Commission are:

- Collection and documentation of source material.
- Critical evaluation and translation of relevant ancient manuscripts of science.
- Organization of seminars and workshops, and
- Publication of the Indian Journal of History of Science, the only journal of its kind in India, started 30 years ago.

Importantly the Academy supports research projects in various areas of history of science and technology by experts, after a critical peer review.

The Commission has brought out over 30 major publications including monographs. Besides the volume, *A Concise History of Science in India*, the list includes *History of Astronomy in India, History of Medicine in India, History of Technology in India* (three volumes) and *History of Metallurgy in India*. Among the earlier publications which have received much appreciation in the scientific world, mention may be made of *Caraka Saṃhitā* (a scientific synopsis, 1960); *Suśruta Saṃhitā* (as scientific synopsis, 1980); The *Sulbha Sūtras* of Baudhayana, Apastamba, Katyayana and Manava with text, English translation and commentary (1983); *Aryabhatia* of Āryabhaṭa, text with English translation (1976); *Rasa Ratna Samuccaya* by Vagbhata edited with English translation, notes and appendixes in two parts (1991-92) and *Jahangir, the Naturalist* (1969).

Information and Reference

The INSA Library and the Computer Centre are the two main wings of the Informatics Centre. The library primarily serves the needs of the Fellows, other scientists/scholars and enrolled members. It renders reference service whenever required and extends facilities for consultation. Presently, it receives more than 800 scientific and technical journals and has a collection of 17,987 books related to Science and Technology, History and Philosophy of Science, Science Education, Management and Science Policy. The Library is also procuring books in Hindi pertaining to S&T area. The library is planning to compile a complete set of publications of each Fellow of the Academy. Besides the regular activities of the library, the Informatics Centre renders the following services to its users:

- *Citation Analysis:* Informatics Centre provides citation analysis against request to the Fellowship based on CD-ROM database of Science Citation Index from 1980 till date. This service is becoming popular among the scientific community.
- *Science Information Notes:* A collection of articles, *SIN*, is brought out on issues of topical interest, covering the latest developments in S&T, Environment, Development Policy, and many other related areas. A special Hindi issue of *SIN* is published in January every year.
- *Current Awareness Service:* Since 1986, Fellows are being supplied with contents pages of selected journals of their choice from the journals received in the library. Subsequently full articles are supplied on request. This service has also been extended to INSA Young Scientists and Institutional Members.
- *Additional Contents Page Service:* Recently an Additional Contents Page Service has been started for the INSA Fellows. Under this service, content pages of 240 journals in various disciplines of S&T, not available in INSA library, are sent to Fellows according to their choice. Copies of these articles can be obtained either from Indian National Scientific Documentation Centre or any other source by the Fellowship directly.
- *Bibliographic Services:* Using electronic resources, bibliographies on specific topics are being compiled and supplied.
- *IT-based Information Services:* Internet based data services and E-mail requirements are available on a limited scale.
- *Electronic Resources:* Acquisition of resources on CD's has been initiated and a few sources have been aquired on CD's. Efforts are being made to

procure more secondary sources in electronic format. Further, the records of INSA Fellows are also being digitised and made available on CD's.

PUBLICATIONS

An important activity of the Academy is to publish Proceedings, Journals, Memoirs, Year Book, etc. The first issue of the *Transactions* of the National Institute of Sciences of India came out in 1935. Three volumes, consisting 26 numbers were published. After the first issue of the fourth volume, the *Transactions* were discontinued and a new series of monographs was started, to enable scientists to publish their research work. In 1936, the NISI brought out *Indian Science Abstracts*, containing an annotated bibliography of all scientific papers published in India. Four volumes - each in two parts - appeared in 1937 and in 1938, and one in 1939. Thereafter this publication was discontinued. The first monograph came out in 1960.

The first issue of the *Proceedings* containing the history of the foundation of National Institute of Sciences of India, its aims and objectives, provisional rules, proceedings of the inaugural meeting and inaugural addresses was published in 1935. *Proceedings* was a bimonthly until 1954, the incorporated articles in both Physical and Biological Sciences. From 1955 onwards, the *Proceedings* are being published in two series - Part A for Physical Sciences, and Part B for Biological Sciences - in alternate months. From 1998 onwards the *Proceedings* has been appearing under two series PINSA – A and PINSA – B. The emphasis has shifted from being vehicles of original research reports but only contain reviews, tracts of contemporary scientific interest as well as to publish primary comprehensive summary reports on specific topics. *Indian Journal of Pure & Applied Mathematics* started January 1970 as a quarterly journal, is now being published every month.

One of the unique publications of the Academy is the *Indian Journal of History of Science*. This is a quarterly journal devoted to studies in various fields of ancient, medieval and modern science in



The President of India, Dr. K.R. Narayanan, visiting the Academy premises.

historical perspective, and offer an interesting forum for scientists, historians, social scientists, philosophers educationists, to gain an insight into the evolution of scientific concepts and technological developments.

From time to time the Academy publishes Status Reports on various scientific disciplines, Proceedings of important multidisciplinary seminars, and special monographs. INSA has also published *Biographical Notes on Fellows of the Academy 1935-93* (two volumes), *Profiles in Scientific Research: Contributions of the Fellows* (five volumes), *Compilation of the Award Lectures* (four volumes) and *Presidential Addresses*.

The Biographical Memoirs brought out each year serve as authentic records for posterity, of the lives and works of deceased Fellows. Twenty two volumes of the Memoirs have been published so far.

The *INSA Year Book* is a useful document. From 1960, it has been brought out every year in January, at the time of the Anniversary General Meeting of the Academy. The Year Book lists the activities of various units of the Academy, details of the Fellowship - both Indian and foreign, composition of the various committees, Rules and Regulations, the calendar of events and other activities of the Academy. INSA News, the in-house journal of the Academy is published bimonthly. It highlights the activities of the Academy and its local chapters and achievements of its Fellowship.